

Problems and development trend of sewage treatment technology in China under the background of carbon neutralization

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Abstract: Under the background of carbon neutralization, carbon neutralization in sewage treatment industry is paid more and more attention to by people. This study summarizes the main emission sources of greenhouse gases in the process of sewage treatment in China, including the direct emission sources of aerobic respiration of sewage treatment microorganisms, nitric oxide produced by nitrification and denitrification, and the indirect emission sources of motors and pumps required in the process of sewage treatment. This study focus on the emission sources of greenhouse gases in the process of sewage treatment and the problems faced by the current sewage treatment technology, summarizes the methods and technical development direction of carbon neutralization in China's sewage treatment plant, including "energy substitution and technology improvement ", "carbon dioxide capture and storage", "sludge cogeneration", "development of new low-energy sewage treatment processes such as short-range nitrification anaerobic ammonia oxidation". It is expected to provide reference and guidance for China to reduce greenhouse gas emissions in the field of sewage treatment and finally achieve the energy conservation and emission reduction goal of carbon neutralization.

Keywords: Sewage treatment; Carbon neutralization; Sludge cogeneration; Shortcut nitrification anaerobic ammonia oxidation

In the process of human development, the excessive emissions of greenhouse gases, such as CO₂, which are produced mainly through the combustion of fossil fuels, have caused global environmental problems. Especially in recent years, the greenhouse effect caused by excessive greenhouse gas emissions has led to climate warming and glacier melting, which have caused large losses to human beings [1]. Therefore, it is very important to control the emission of CO₂ and other greenhouse gases in the production and living process, and finally achieve "carbon neutrality" while achieving technological progress and improving the quality of human life [2]. The concept of "carbon neutrality" means that the total amount of CO₂ and other greenhouse gas emissions produced directly or indirectly by a country, enterprise or individual within a certain period of time can be offset by planting trees, energy conservation and emission reduction to achieve positive and negative offsetting of CO₂ or other greenhouse gas emissions produced by themselves to achieve a relative " zero emissions" [3].

This concept of "zero carbon emission" was first proposed in 1997, and has gradually received attention from various countries and organizations around the world. In recent years, with the rapid development of science and technology in China, people's demand for improving living standards, achieving green and healthy development, and energy saving and emission reduction in all industries has become more and more urgent [2]. In the 75th session of the United Nations General Assembly, our country announced to achieve "carbon neutrality" by 2060, which is not only beneficial to the survival and development of all human beings, but also the way to achieve low-carbon environmental protection and efficient development of our country. Wastewater contains a large amount of organic and inorganic substances containing carbon, nitrogen, phosphorus and other elements, which are present in the wastewater as resources and energy sources [4]. Currently, wastewater treatment is mainly done by physical, chemical and biological methods to purify and treat wastewater [5]. The process of wastewater treatment produces a large amount of greenhouse gases: the respiration of microorganisms consumes organic matter in wastewater and releases CO₂ [6]; the biological denitrification process releases a large amount of nitrous oxide (N₂O), while some studies have confirmed that the greenhouse effect of N₂O is 300

times greater than that of CO₂ [7]. Therefore, achieving carbon neutrality in the wastewater treatment process and achieving green sustainability in wastewater treatment technology has attracted increasing attention from researchers. Currently, after more than a decade of development, the research and practice of achieving carbon neutrality in the wastewater treatment process in Europe and the United States and other developed countries have been reported several times: by replacing fans with higher efficiency and optimizing fan performance, the Grunee wastewater treatment plant in Germany increased the energy self-sufficiency of the plant by more than 8% [8]. Using denitrifying phosphorus accumulating bacteria for both nitrogen removal and phosphorus removal, a wastewater treatment plant in the Netherlands used a novel biological phosphorus removal process (BCFS) that not only increased the production of CH₄ by 154%-274% but also reduced the consumption of carbon sources by 53%-59%. The reduction in aeration energy consumption was accompanied by a reduction in CO₂ 16%-21% [8]. In Finland, on the other hand, the Kakolanmaki wastewater treatment plant, which uses the traditional activated sludge method anoxic/aerobic process (A/O), subjected the sludge to anaerobic fermentation and composting processes, collected the biogas produced, and used the biogas to produce heat and electricity, both to supply energy to the wastewater treatment plant and to provide electricity and heating to the area [8]. This not only effectively combines energy use and heat recovery, increasing the proportion of renewable energy for heating in the city where this wastewater plant is located, but also, some of the remaining sludge can be used as raw material for fertilizer, as well as converted into a land improver, reducing carbon emissions by 80,000 tons per year [8]. At present, in China, wastewater treatment technology mainly uses activated sludge method, including A/O process, modified A₂/O process, oxidation ditch process, biofilm (MBR) method, and SBR process [9]. During the treatment of wastewater by activated sludge method, the respiration and nitrification of microorganisms release large amounts of greenhouse gases such as CO₂ and N₂O [10]. Moreover, the backwardness of wastewater treatment equipment and processes, rough management of wastewater treatment plants, and unreasonable disposal of residual sludge in our country lead to the consumption of a large amount of energy and the release of a large amount of greenhouse gases in the process of wastewater treatment, for example, the aeration units and lifting pumps in the process of wastewater treatment, both of which generally consume more than 70% of energy [11]. Therefore, it is increasingly urgent for China to reduce greenhouse gas emissions in the wastewater treatment process, achieve low-carbon operation, and eventually achieve the goal of carbon neutrality. Therefore, in this paper, by summarizing the main sources of greenhouse gas generation in the wastewater treatment process and combining the successful experiences of energy saving and emission reduction in the wastewater treatment field at home and abroad, the paper focuses on "energy substitution and technology upgrading in wastewater treatment process", "carbon dioxide capture and sequestration", "sludge cogeneration", "development of new low-energy wastewater treatment processes", etc., and summarized the reasonable measures to achieve the goal of carbon neutrality in the field of wastewater treatment in China. It is expected that this paper will provide some reference and guidance for our country to achieve the goal of carbon neutrality in the field of wastewater treatment.

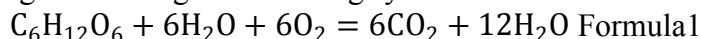
1. Sources of greenhouse gases in wastewater treatment process

The process of wastewater purification and treatment generally consumes a large amount of energy and emits a large amount of greenhouse gases [12]. In the wastewater treatment process, the most important ways of carbon emissions include direct and indirect emissions [13]. Among them, carbon emissions due to microbial respiration, anaerobic digestion and nitrification and denitrification are direct emissions. Carbon emissions due to energy consumption (motors, aeration devices), chemical addition and sludge disposal process are indirect emissions.

1.1 Direct emissions of greenhouse gases in wastewater treatment process

1.1.1 Aerobic respiration of microorganisms

Wastewater is rich in carbonaceous organic matter [12]. According to the mechanism of organic matter consumption by microorganisms under aerobic conditions (Equation 1), organic pollutants in wastewater are converted into CO₂ and H₂O by relevant enzymes in microorganisms in an environment with good oxygen conditions. the remaining part of organic matter, which is used by microorganisms and synthesized into microbial cells, eventually exists in the form of residual sludge [14]. However, according to the 2006 National Greenhouse Gas Inventory Guidelines, the CO₂ released from the decomposition of organic matter in wastewater by microorganisms comes from atmospheric CO₂ absorbed by plants in nature through photosynthesis, and this process should be part of the natural carbon cycle and does not cause a net increase in atmospheric CO₂. However, it has been pointed out that organic matter used for washing purposes contains about 20% of organic carbon [15]. Therefore CO₂ produced by microbial aerobic action should be counted as in the greenhouse gas accounting system.



1.1.2 Anaerobic digestion During wastewater treatment,

Organic matter is converted into organic acids by anaerobic or partly anaerobic microorganisms, and organic acids can be decomposed into CH₄, CO₂, and H₂O by the digestion of methanogenic bacteria (Figure 1) Some studies have proved that CH₄, as a potent greenhouse gas, has a greenhouse effect 21 times greater than that of CO₂ [17]. It has been reported in the literature that the wastewater treatment process produces about 5% of the total emissions of CH₄ [17,18]. Therefore, the emission of CH₄ during wastewater treatment should be controlled as much as possible. Usually, CH₄ is easily generated during wastewater transport pipelines, sludge transportation and sludge treatment [19].

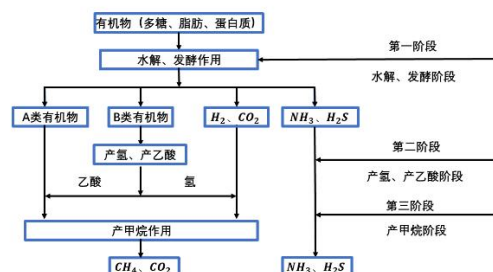


Fig.1 Anaerobic digestion process

1.1.3 Nitrification and action denitrification

The biological denitrification process of wastewater mainly consists of nitrification and denitrification (Figure 2). Usually, in the actual wastewater treatment process, a large amount of N₂O is generated due to low carbon source content or the ratio of carbon to nitrogen [20]. It has been noted that N₂O produced during actual scale wastewater treatment is about 14.6% of the total nitrogen in the influent [18]. And the greenhouse effect of N₂O is 300 times higher than that of CO₂ [19]. Therefore, the large amount of N₂O produced by nitrification and denitrification during wastewater treatment is also an important greenhouse gas source.

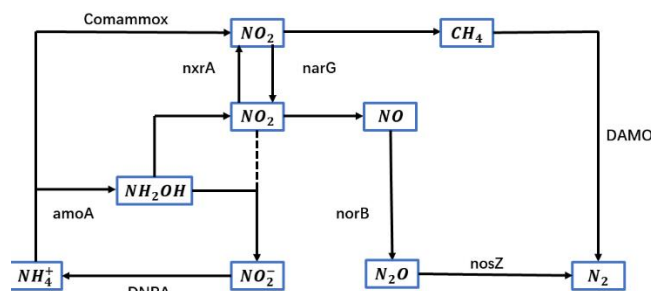


Fig.2 Nitrification and denitrification process

1.2 Indirect emissions of greenhouse gases in the wastewater treatment process

1.2.1 Energy consumption

Many processes in wastewater treatment plants require the consumption of electrical energy during the treatment of wastewater, and today fossil fuel power generation is still the main method, which is one of the causes of indirect emissions of greenhouse gases [21]. Pumps and motors are used in the wastewater treatment process, which consume electrical energy to separate or recover pollutants from the wastewater. Moreover, a large amount of oxygen needs to be consumed in the aerobic stage of wastewater treatment, so aeration is also a high energy-consuming aspect that causes more than 50% of energy consumption in wastewater treatment [18], such as the BOD5 unit water consumption index of electricity used to evaluate the electrical energy consumption of aeration link in a wastewater treatment plant in South China reaches 2.449 [22]. According to statistics, as of 2017, China has a total of more than 5000 wastewater treatment plants [23], and the total electricity consumed by wastewater treatment in 2017 was about 25.231 billion kW-h, accounting for about 0.4% of the total social electricity consumption [20]. Electricity consumption accounts for about 60% to 90% of the comprehensive energy consumption in the wastewater treatment process [20]. At present, China currently relies mainly on coal-fired power generation, for example, in some coastal areas thermal power generation accounts for more than 85% of the total power generation [18], and the large amount of electricity consumption in the wastewater treatment process will cause indirect emissions of greenhouse gases.

1.2.2 Pharmaceutical additions

To improve the quality of the effluent, chemicals and flocculants are usually added to the wastewater and sludge treatment process [17]. Studies have shown that the carbon to nitrogen ratio has a great influence on the removal of nutrients such as nitrogen and phosphorus in the denitrification process [18]. When the carbon source is insufficient, organic carbon sources such as methanol need to be added to increase the carbon to nitrogen ratio in the wastewater treatment process to improve the nitrogen and phosphorus treatment efficiency. However, the addition of methanol increases the CO₂ emissions in the system. Studies have confirmed that each g of methanol input produces approximately 1.54 g of CO₂ as measured by greenhouse gas emission factors [24]. Similarly, a large amount of flocculant is used in wastewater treatment to achieve solid-liquid separation of wastewater, but a large amount of indirect emissions of chemically related greenhouse gases are produced. One study showed that in a wastewater treatment plant, the A/O process consumed about 0.127 kg/m³ effluent of polyvinyl chloride and 0.230*10⁻³ kg/m³ effluent of polyacrylamide [25]. This wastewater treatment plant generated additional greenhouse gases due to flocculant dosing, e.g., the A/O process in this wastewater treatment plant generated an additional indirect amount of greenhouse gases of 205.81 gCO₂-eq/m³ effluent and the SBR process in this wastewater treatment plant, an additional indirect amount of greenhouse gases of 330.05 gCO₂-eq/m³ effluent [25]. Therefore, the addition of pharmaceuticals in the wastewater treatment process is also an important indirect GHG emission pathway in the wastewater treatment process.

1.2.3 Residual sludge treatment

The large amount of residual sludge generated in the wastewater treatment process, the pharmaceuticals added in the subsequent treatment process, and the energy consumed can lead to indirect GHG emissions [18]. The main methods of sludge treatment are currently aerobic composting, sanitary landfill, anaerobic digestion and dry incineration [13]. Studies have demonstrated that each ton of residual sludge disposed by anaerobic digestion generates 960.19 kgCO₂-eq/t of carbon emissions [26]. Disposal by sanitary landfill generates 1587.59 kg CO₂-eq/t of carbon emissions, while 731.38 kg CO₂-eq/t of carbon emissions are generated by aerobic composting [25]. Therefore, the existing residual sludge treatment methods produce a large amount of greenhouse gases, and it is important to explore new residual sludge treatment methods to reduce greenhouse gas emissions in the wastewater treatment process.

2. Development trend of wastewater treatment technology in the context of carbon neutrality

Recent years, domestic biotechnology, material science, and computer technology have been developed rapidly in the context of carbon neutrality. Researchers on the energy conversion of the sewage treatment process, microbial action principles and other research more and more in-depth, while with the gradual application of chemometrics and computer technology in the biochemical and physical-chemical treatment of pollutants and the development of new materials and new equipment, so that the interactions of various aspects of the sewage treatment process tends to mathematical quantitative characterization, and in this way the sewage treatment process for reasonable control and timely treatment, including drug Timely and quantitative input, automatic control of aeration tanks and other wastewater treatment facilities, monitoring of greenhouse gas emissions, etc. In addition, the development of new wastewater treatment technologies such as carbon dioxide capture and storage technology, cogeneration in the wastewater treatment process, anaerobic denitrification for phosphorus removal, and short-course nitrification-anaerobic ammonia oxidation continues to advance [27]. The combined use of these technologies not only improves the efficacy and management benefits of wastewater treatment, reduces the cost of wastewater treatment, but also greatly reduces the emission of greenhouse gases in the wastewater treatment process.

2.1 Energy substitution and technology enhancement in wastewater treatment process.

2.1.1 Application of energy-efficient green energy technologies

Sewage treatment plants generally cover a large area, and some of the treatment process components also have a large surface area, such as reaction ponds, sedimentation tanks, filter ponds, and other units, so that the application of fossil energy can be reduced by installing photovoltaic modules in sewage plants and using light energy to generate power for their electricity-using equipment, which in turn reduces the emission of greenhouse gases such as CO₂ from the source. Some studies have shown that on average, 1147-1576 m² of photovoltaic modules can be laid on top of a wastewater treatment plant per 10,000 tons of wastewater treatment size, and the daily power generation can compensate about 10% of the power consumption of the wastewater power plant [28]. For example, the Damhusåen wastewater treatment plant in Copenhagen has PV modules installed on the surface of its treatment process to meet 9% of the energy demand in the study area [29]. In addition, a wastewater treatment plant in Henan Province will be able to reduce 33 million KW-h of production electricity and about 32,900 t of CO₂ emissions per year by installing 17 MW of photovoltaic modules [27]. Therefore, widely promoting the use of new power generation technologies such as wind and electrical energy to supply power to wastewater treatment plants can not only supplement the power consumption of wastewater treatment plants, but also reduce greenhouse gas emissions.

2.1.2 Upgrading and optimizing the aeration system of wastewater treatment plants

The aeration tank of wastewater treatment plants not only provides oxygen for aerobic bacteria (such as ammonia oxidizing bacteria), but also agitates the activated sludge in the tank to increase the efficiency of wastewater treatment. It plays a key role in the aerobic aspect of wastewater treatment [30]. Studies have shown that the main aeration system of aeration tanks in wastewater treatment plants consumes 50%-70% of the total electricity required for wastewater treatment [31]. By optimizing the aeration system, it is possible to achieve both a reduction in energy consumption and indirect emissions of greenhouse gases, as well as to ensure the effluent quality of the wastewater treatment plant. For example, the traditional (Proportional-Integral-Derivative) PID control and fuzzy PID control, which control the dissolved oxygen concentration, and the precise aeration flow control, which is mainly controlled by air flow in recent years [28]. Compared with traditional optimization means, precise aeration flow control can also be combined with computers to precisely and finely control the required air volume according to the changes in water quality and quantity, further reducing energy consumption [31].

2.1.3 Optimization of dosing link

Wastewater treatment often requires the addition of some flocculants, reaction reagents, etc., which are beneficial to the efficient treatment of pollutants in the wastewater. However, as some additional drugs added contain elements such as carbon and nitrogen, greenhouse gases can be produced after the reaction [18]. Therefore, how to dose, when to dose, and input quantity control under the condition of ensuring water quality become the key points to optimize the dosing system. Nowadays, the development of computer digital technology provides new ideas for optimizing the dosing system, using mathematical models, online detection instruments, and variable frequency agent dosing pumps to form an accurate dosing system [32]. On the basis of ensuring that the effluent water quality meets the standards, the pharmaceutical dosing is saved and the energy consumption and greenhouse gas emissions are reduced. For example, in a wastewater treatment plant, after investigation and calculation, a study found that the actual dosage in the wastewater treatment process is as much as six times the theoretical dosage, and the precise dosage through computerized digital technology not only increases the treatment efficiency from 96.12% to 98.17%, but also reduces the daily PAC dosage by 10.5% [30]. It reduces both greenhouse gas emissions and operating costs.

2.1.4 Using artificial intelligence to improve the operational efficiency of wastewater treatment plants

Wastewater treatment systems are variable, nonlinear, and time-varying, and the use of artificial intelligence can be a good way to monitor changes in relevant data during the wastewater treatment process [33]. The more widely used is the use of artificial neural networks to measure COD, BOD, nitrogen, phosphorus and other parameters, estimate the quality of the influent water, decide the size of aeration and reaction time, and achieve real-time control of the wastewater treatment process. Ren Min et al. used BP neural network to analyze the data of the actual operation of wastewater treatment, and the final results matched with the actual results, which can be achieved both to improve the reliability of the wastewater treatment process and to reduce the consumption of energy [34]. Fuzzy calculations can also be used to achieve a reduction in the concentration of suspended matter in the effluent, reduce the concentration of effluent BOD and COD, and ensure the stable operation of the treatment system, for example, YPTsai uses dynamic activated sludge method fuzzy control to adjust the water intake to achieve control of the concentration of effluent BOD or COD [31].

2.2 Development of carbon dioxide capture and sequestration technology

Wastewater itself is rich in energy and resources, which can be fully utilized, it can be converted into clean energy and supplied for use. Traditional wastewater treatment processes are aimed at reducing the concentration of pollutants in wastewater and improving water quality, and these

treatment processes often consume a large amount of energy to complete the removal of pollutants, which is not only not an economically sustainable process, but also emits a large amount of greenhouse gases into the environment. According to studies, untreated wastewater contains carbon source energy, which requires about 9 to 10 times more energy to treat [35]. If these carbon sources can be captured and collected, not only the goal of "carbon neutral" wastewater treatment plants can be achieved, but also the energy in the wastewater can be used to supply electricity and heat the area. Currently, there are three stages of carbon dioxide capture and storage: capture, transport and storage. In the capture phase of CCS, three main technologies are used to capture CO₂: pre-combustion capture, oxygen-enriched combustion, and post-combustion capture [36]. Currently, the post-combustion capture process is mainly used to collect the waste gas generated from the combustion of fossil fuels and to separate CO₂ by using liquid solvents and heating [33]. In a sense, there is no major difference in the composition of CO₂ generated in the wastewater treatment process from that generated after fossil fuel combustion, and given the similarity between them, the post-combustion capture process can be borrowed to capture CO₂ generated in wastewater treatment [33]. Then, three main technologies, namely geological, marine and chemical storage, can be used to capture CO₂ for oil exploration and to convert it into carbonates for permanent storage in the ocean [33]. However, although the use of CO₂ capture and storage technology will greatly reduce CO₂ emissions from wastewater treatment and can effectively reduce greenhouse gas emissions, there are still many obstacles to the application of this technology to the wastewater treatment process. The main reason is that the technology is currently too difficult, many projects are still in the experimental stage and cannot yet be promoted on a large scale, and some projects have not yet achieved large-scale innovation [34].

2.3 Sludge cogeneration

The wastewater treatment process is often accompanied by the production of residual sludge, and greenhouse gases such as CO₂, N₂O, and CH₄ are produced while treating the residual sludge [13]. Among the many sludge treatment processes, anaerobic digestion treatment is the most widely used, which is technically mature, has low energy requirements, and can produce biogas [37]. The collection of biogas and its application for electricity and heat generation not only reduces the emission of greenhouse gases produced by sludge, but also harnesses the energy it contains. Methane production from anaerobic digestion of sludge implements Combined heat and power (CHP), which is an advanced form of energy utilization that can produce both electricity and heat [38]. In this way, the methane produced during the anaerobic digestion of residual sludge can be collected and the energy contained in the sludge can be recovered. For example, a German wastewater plant can meet 57% of the electrical energy consumption of the entire water plant using methane produced by sludge digestion [38]. Countries such as Sweden and Denmark use the heat generated by cogeneration to heat the corresponding areas. However this technology can also be limited by the methane production [39]. Most wastewater treatment plants treat wastewater with low organic matter content, making the amount of residual sludge produced after treatment low, resulting in insufficient methane production from anaerobic digestion for stable methane collection and energy self-sufficiency. For this problem, high concentration organic waste such as kitchen waste [40], garbage leachate, and farming wastewater [41] can be anaerobically digested together with residual sludge, which can compensate for the lack of organic energy.

2.4 Development of low energy consumption wastewater treatment process

Currently, the activated sludge method process (A₂O/SBR, etc.) commonly used in China's wastewater treatment plants has high energy consumption and serious greenhouse gas emission problems [42]. In the context of carbon neutrality, China's wastewater treatment plants must explore and develop new wastewater treatment processes to achieve the goal of low-carbon operation of wastewater treatment. At present, new low-carbon and efficient water treatment processes such as short-range nitrification-coupled anaerobic ammonia oxidation (PN-A) process, denitrification for

phosphorus removal, and microalgae resource-based technology for wastewater treatment are receiving increasing attention from researchers. Compared with the existing activated sludge method, these new wastewater treatment processes can significantly reduce carbon source consumption, energy consumption, and greenhouse gas emissions [43]. Studies have shown that the PN-A process relies mainly on anaerobic ammonia oxidizing bacteria to couple ammonia and nitrous nitrogen to produce nitrogen gas to remove pollutants from the water column. Anaerobic ammonia oxidizing bacteria are inorganic autotrophic bacteria, and using this process to treat wastewater can not only reduce the dosage of chemicals by 100%, but also reduce the energy consumption by 60%, as well as reduce the amount of sludge produced after treatment [44]. However, there are many limitations in the application of anaerobic ammonia oxidation process in mainstream wastewater due to factors such as low temperature of mainstream wastewater, low concentration of ammonia nitrogen, and influence of organic matter [44]. In the future, the research on the application of PN-A process in mainstream wastewater treatment is the main research direction to reduce the energy consumption of wastewater treatment and achieve low-carbon operation of water treatment. In addition, some researchers have found that parthenogenic denitrifying polyphosphorus bacteria can save about 50% of COD and 30% of O₂ and correspondingly reduce 50% of residual sludge volume by using PHA, an energy storage material in cells, as a carbon source for excessive phosphorus uptake during denitrification and phosphorus removal [8]. It has been found that microalgae can decompose organic matter to produce CO₂ and O₂ when wastewater rich in nitrogen and phosphorus elements is fed into a photobioreactor under light. therefore, the resourcefulness of wastewater through microalgae can not only achieve the purpose of wastewater treatment, but also realize the recycling of wastewater resources [43]. With the progress of society and the improvement of human production and living standards, the composition of wastewater is becoming more and more complex, which puts forward higher requirements for the innovation of future wastewater treatment technology.

3. Summary

Under the background of carbon neutrality, how to reduce the carbon emission in the wastewater treatment process is a hot spot of concern in the field of wastewater treatment. This paper summarizes the main sources of greenhouse gases in the current wastewater treatment process, including direct emissions from biological respiration, anaerobic digestion, nitrification denitrification, and indirect emissions caused by residual sludge disposal, chemical dosing, aeration energy consumption, etc. In order to achieve the goal of carbon neutral operation in wastewater treatment industry as soon as possible, reduce the energy expenditure in the wastewater treatment process, and mitigate and reverse the adverse effects of global climate change due to greenhouse gas emissions, this paper summarizes the methods to reduce carbon emissions and achieve carbon neutral operation in China's future wastewater treatment plants, including "energy substitution and technology upgrading in wastewater treatment process This paper summarizes the future approaches to reduce carbon emissions and achieve carbon neutral operation of wastewater treatment plants in China, including "energy substitution and technology upgrading in wastewater treatment process", "carbon dioxide capture and storage", "sludge cogeneration", and "development of new low energy consumption wastewater treatment processes".

References

- [1] Liu Qingliang,Wang Rufe, Ma Jun. Challenges of urban water supply under the vision of carbon neutrality, safety and security measures and technological research progress[J]. Water Supply and Drainage,2022,58(01):1-12.DOI
- [2] Correct understanding and grasp of carbon neutral of Carbon Dafeng[N]. Liaoning Daily,2022-04-19(005).

- [3] Deng X, Xie J, Teng F. What is "carbon neutral"? What is "carbon neutrality"? [J]. Climate Change Research Progress, 2021, 17(01): 107-113.
- [4] Chen Junren, Zhang Libin, Liu Qingqing et al. Advances in research on microalgae cultivation from waste leachate: Towards carbon neutrality [J/OL]. Industrial Water Treatment: 1-14 [2022-05-29].
- [5] Zhang Mei. Discussion on quality control of urban wastewater treatment methods and wastewater laboratory analysis [C]//Proceedings of 2020 Wanchi Science Development Forum (Wisdom Engineering III). , 2020: 82-90.
- [6] Jiang Libing, Liu Jinxin, Dong Jinbo et al. Current status of research on carbon dioxide emissions from urban wastewater treatment plants [J]. Shandong Chemical Industry, 2021, 50(22): 222-224+227.
- [7] Liu W. B. Generation and release of non-CO₂ greenhouse gases from different municipal wastewater treatment processes [D]. Xi'an University of Architecture and Technology, 2013.
- [8] Yang Q, Wang Yaxin, Cao Xuxin et al. Advances in carbon neutral operation technology for wastewater treatment [J]. Journal of Beijing University of Technology, 2022, 48(03): 292-305.
- [9] Wang Qian, Li Jiangwei, Wang Zhigang et al. Analysis of energy consumption of key equipment in urban wastewater treatment plants and research on ways to save energy and reduce consumption [J]. Water Supply and Drainage, 2018, 54(10): 44-47.
- [10] Yu Jiaxin, Wu Fanjie, Yang Xiaoliang. Exploration of the application of activated sludge method in wastewater treatment [J]. Green Technology, 2016(02): 66-67.
- [11] [Yang KAM Xiang, Wan L, Wang H, Yu D. Analysis of energy consumption in wastewater treatment plants and measures and applications of energy saving and consumption reduction [J]. Resource Conservation and Environmental Protection, 2021(10): 12-14.
- [12] Wang Liyan, Zhang Jinchao. Carbon dioxide emission and carbon resource utilization in urban wastewater treatment [J]. Green Technology, 2012(06): 198+200.
- [13] Guo Cha. An analysis of carbon emission accounting boundary in the process of sludge treatment and disposal in urban wastewater plants [J]. Water purification technology, 2019, 38(10): 131-134+142.
- [14] Liu Kun. Analysis of greenhouse gas emissions and emission reduction methods of urban wastewater treatment plants [J]. Urban Geography, 2017(04): 138.
- [15] Zhang Yue, Ge Tonggang, Sun Yongli et al. Research on carbon emission model based on the whole process link of urban wastewater treatment [J]. China Water Supply and Drainage, 2021, 37(09): 65-74.
- [16] Zheng S-W, Tang W, Xu H-Lan et al. Research on estimation of methane emissions from urban wastewater treatment plants and control measures [J]. Water Treatment Technology, 2016, 42(12): 46-49.
- [17] Guo Jingbo, Tian Yu, Zhang Lanhe et al. Greenhouse gas emissions from urban wastewater treatment plants and countermeasures for emission reduction [J]. Chemical Progress, 2012, 31(07): 1604-1609+1624.
- [18] Huang Chao, Zheng Yan, Zhu Ling. Research on the development status, environmental impact and countermeasures of thermal power generation in coastal areas of China [J]. Marine Economy, 2020, 10(01): 22-27.
- [19] Zhao Qianying. Carbon emission modeling and carbon neutral operation potential measurement of wastewater plants [D]. Shenyang University of Architecture, 2018.
- [20] Yang Qian. Study on the characteristics and influencing factors of N₂O changes in sludge treatment system [D]. Shaanxi University of Science and Technology, 2018.
- [21] Yan X, Han Yunping, Li Qilu et al. Research progress on greenhouse gas generation in wastewater treatment process [J]. Environmental Chemistry, 2015, 34(05): 853-862.
- [22] Long L. P. Study on energy consumption analysis and energy saving measures of urban wastewater treatment plants [J]. Engineering Technology Research, 2019, 4(14): 239-240.
- [23] Yang Cui-Li, Wu Zhan-Hong, Han Hong-Gui et al. Research progress of optimization setting method for urban wastewater treatment process [J]. Journal of Automation, 2020, 46(10): 2092-2108.
- [24] Chai Chunyan. Research on greenhouse gas emission law and heat island effect of urban wastewater treatment plant [D]. Harbin Institute of Technology, 2017.
- [25] Bao Zhiyuan. Research on greenhouse gas emission characteristics and emission reduction strategies of typical urban wastewater treatment process [D]. Beijing Forestry University, 2019.

- [26] Li Qiaoyang. Research on the status and development trend of urban sludge disposal in China based on carbon emission reduction analysis[D]. Harbin Institute of Technology, 2020.
- [27] Wang T, Tian K, Li J. Current status of research on factors influencing the enrichment process of anaerobic ammonia oxidizing bacteria[J]. Petrochemicals should
- [28] Si Xianpei. Application of photovoltaic power generation technology and Internet of things technology in rural domestic wastewater treatment[J]. Solar Energy,2021(09):52-56.
- [29] Lv Liping,Li Hang,Li Wei et al. Practical approaches and application progress of carbon neutralization in wastewater treatment plants[J/OL]. Industrial Water Treatment:18[2022-05-29].
- [30] Zhang Royan. A study on the renovation of aeration system in a wastewater treatment plant in Zhejiang[J]. Guangzhou Chemical Industry,2020,48(10):138-140.
- [31] Deng Huanzhong,Xu Wenli,Lin Meishan et al. Application of precise aeration flow control system in wastewater treatment plants[J]. Water Supply and Drainage,2019,55(S1):51-54.
- [32] Guo Yumei,Liu Bo,Guo Fang et al. Analysis of the operation effect of precise dosing system for tertiary treatment in wastewater treatment plants[J]. Environmental Engineering,2018,36(09):26-29.
- [33] Wang Chao. Application of artificial intelligence in wastewater treatment [J]. Experimental Science and Technology,2005(S1):170-172.
- [34] Ren Min, Wang Wanliang, Li Tanwei, et al. Research on soft measurement system for wastewater treatment based on neural network[J]. Automation Instrumentation,2001(10):10-11.
- [35] Wang Liyan,Zhang Jinchao. Research on carbon dioxide emission and carbon resource utilization in urban wastewater treatment[J]. Green Technology,2012(06):198+200.
- [36] Chen F,Yao R. Carbon dioxide capture and storage technology[J]. Energy Research and Information,2011,27(04):193-196+202.
- [37] Yu Xiaofeng. Optimization design of biogas cogeneration system in wastewater treatment plant[D]. Qingdao University of Technology,2019.
- [38] Yu Xiaofeng,Zhou Enze,Ding Xuefeng et al. Optimization analysis and performance evaluation of biogas cogeneration system in wastewater plant based on TRNSYS[J]. Journal of Solar Energy,2021,42(10):324-330.
- [39] Sun Hongyang. Analysis of methane production efficiency of coupled sludge anaerobic digestion-microbial electrolysis process[D]. Harbin Institute of Technology,2014.
- [40] Liu L, Liu T. Study on the influencing factors of anaerobic digestion of kitchen waste[J]. China Resource Utilization,2021,39(09):155-157.
- [41] Zhang Zhen. Research on anaerobic digestion and short-range nitrification process of farm wastewater[D]. Hefei University of Technology, 2021.
- [42] Xu Yufeng. Research on pollution removal and sludge reduction by hypoxic activated sludge method[D]. Chongqing University, 2014.
- [43] Wang Guiquan. Progress and prospect of application of microalgae resourceization technology for wastewater treatment in the context of carbon neutrality[J]. Leather Making and Environmental Protection Technology,2021,2(24):161-163 [44] Li Rexiang,Wang Xin,Li Tian. Research progress of microbial nitrogen conversion process for low carbon wastewater[J/OL]. Industrial Water Treatment:1-25[202205-29].