Current Situation and Prospect in Urban Sewage Treatment Plants

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Abstract. Sewage is the carrier of resources and energy, which contains great chemical energy and heat energy. The traditional sewage treatment process consumes energy, and the energy consumption is high. Under the background of carbon neutrality, China's urban sewage treatment plants have achieved carbon neutrality operation in terms of energy self-sufficiency and reduction of greenhouse gas emissions. To explore the feasibility of carbon neutrality in sewage treatment plants, the cases of carbon neutrality in sewage treatment plants at domestic and abroad were analyzed. And the implementation approaches and main emission reduction processes to achieve carbon neutrality were summarized. The technical challenges and research directions of future sewage treatment plants in China from the perspective of carbon neutrality are proposed.

Keywords: Carbon neutrality; sewage treatment plant; low-consumption; energy recovery; carbon emission.

1. Introduction

Since the 21st century, the problem of global warming has become increasingly serious and urgent. In 2020, China promised to reach the carbon peak in 2030 and achieve carbon neutrality in 2060. The carbon emissions of the sewage treatment industry account for 1 % ~ 2 % of China's total carbon emissions [1]. Therefore, the carbon emissions generated during the sewage treatment process cannot be ignored. According to statistics, as of 2019, China's urban sewage production was $5.546 \times 10^{10} m^3$, sewage treatment energy consumption accounts for about 0.73 % of the total social electricity consumption, and greenhouse gas emissions reached 91 million tons of carbon dioxide equivalent (2014) [2,3]. Under the background of national carbon neutrality, the green and low-carbon operation is the transformation direction of urban sewage treatment. Generally speaking, the carbon-neutral operation of urban sewage treatment plants has a specific definition, namely energy balance: recovering the energy in sewage to feed back the energy consumption of urban sewage treatment plants to achieve energy self-sufficiency, while reducing the life cycle of sewage treatment plants to make greenhouse gas emissions achieve carbon neutral operation.

To promote the development of carbon neutralization technology in sewage treatment plants, this paper summarizes the latest progress of carbon neutralization technology in sewage treatment plants through the interpretation and analysis of carbon neutralization cases in five blow treatment plants at domestic and abroad. The aim is to provide a reference for the realization of carbon neutralization operations in urban sewage treatment plants in China.

2. Present Situation of Carbon Neutralization in Sewage Plants

2.1 Carbon neutralization status of foreign wastewater treatment plants

Global warming climate crisis is imminent, and countries around the world for this. Based on the goal of carbon neutrality, industries minimize environmental loads while reducing energy consumption. The need for sustainable development is driving new developments in wastewater treatment. These developments are driven by two forces: the improvement of the process flow and the recovery of resources [4]. Achieving carbon neutrality in sewage plants is the goal of the sustainable development of sewage plants in the future [5]. Some countries in the world have been at the forefront of carbon neutrality, and have successively issued a road map to achieve carbon neutrality in sewage plants, providing the advanced experience for the sustainable development of sewage treatment in the world. The Sheboygan wastewater treatment plant in the United States has realized the self-sufficiency of energy in the treatment process through the operation strategy of open source and throttling. As a model of the operation of the wastewater treatment plant in the United States, the plant has achieved a ratio of electricity production to power consumption exceeding 90 %, and a ratio of heat production to heat consumption

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exceeding 85 % [6]. The Netherlands defines carbon neutrality in wastewater treatment plants as a NEWs framework. Sustainable wastewater treatment is nutrient, energy, and reclaimed water, essentially [7]. Based on this concept, the Netherlands will gradually achieve the goal of carbon neutrality. The Steinhof wastewater treatment plant in Germany makes full use of nitrogen, phosphorus, and other resources in wastewater and reuses the treated water resources and sludge. The total exogenous CO_2 of the plant is reduced by 114 %, which can exceed the carbon neutralization target [8]. O.NOWAK et al. [9] analyzed the Wolfgangsee-Ischl wastewater treatment plant and Strass wastewater treatment plant in Austria. The results show that the power generation capacity of the wastewater treatment plant can reach 180 % compared with the energy demand, and the sewage was converted into cooling water as the heat source of the district heating heat pump, which could save up to 45 % of the electricity.

2.2 Carbon neutralization status of domestic wastewater treatment plants

To cope with the problems of water resources and carbon emissions in the future, some foreign wastewater treatment plants are at the forefront of the world in terms of resource recovery and energy utilization. They provide valuable experience for domestic sewage plants to achieve carbon neutrality. Advanced cases of sewage plants in the United States, the Netherlands and Germany, and other countries show that it is feasible to achieve carbon neutrality in sewage plants, and China should also adapt to local conditions. Limited by the technical level of the development of the water industry and many other factors, China has not yet built a truly carbon-neutral sewage plant. Compared with developed countries such as the United States, China's future-oriented concept of sustainable sewage treatment plants was proposed late. In 2014, Academician Qu proposed 'building a future-oriented Chinese sewage treatment concept plant'. In the future, the operational objectives of sewage treatment plants will change from pollutant reduction to water resource reuse, resource and energy recovery, and water ecological restoration [10]. Resource-oriented sewage treatment has gradually become the theme of the future pursuit of the global water treatment industry. China will also actively explore the development path of sewage plants. In the future, China's new concept of sewage treatment plants will achieve the goal of carbon neutrality based on water purification. Based on this concept, some sewage plants in China have begun to explore new modes of sewage treatment. Henan Shangqiu Suixian Sewage Treatment Plant can be regarded as the 1.0 version of the future sewage treatment plant in China. Jiangsu Yixing New Concept Sewage Treatment Plant further builds the sewage treatment plant as a resource plant on version 1.0, opens a new construction concept, and builds the traditional sewage treatment plant into a sustainable development sewage treatment plant for the future.

3. Process development of carbon neutral operation in urban sewage treatment plants

The organic matter in urban sewage is an energetic substance, and its chemical oxygen demand contains the lowest energy of 13-14 kJ / g. In the traditional sewage treatment process, most of the energy is directly mineralized into CO_2 and lost. If captured and converted, it is expected to offset energy input and even external use of production capacity [11]. The key to achieving carbon-neutral operation of municipal wastewater treatment plants is low energy consumption operation and energy recovery, while traditional treatment processes (aerobic aeration, nitrification-denitrification, etc.) are difficult to achieve, and new processes need to be developed. Researchers generally believe that energy can be recycled through 'carbon capture' technology supplemented by anaerobic digestion-cogeneration, heat recovery, and other technologies [12]. At the same time, the use of technologies such as autotrophic nitrogen removal and denitrifying phosphorus removal can reduce energy consumption, thereby achieving carbon neutrality in sewage treatment plants [13].

3.1 Carbon capture technology

The 'carbon capture' technology based on sewage treatment refers to capturing COD in the influent into the sludge and generating energy through anaerobic digestion of the sludge. It is generally to increase the COD capture in the primary treatment of sewage treatment plants to increase energy production [14]. 'Carbon capture ' technology is mainly realized by high rate activated sludge process(HRAS) [15] and chemically enhanced primary treatment process(CEPT) [16].

(1) HRAS

Because of its short hydraulic retention time(HRT), sludge retention time(SRT), and high sludge load, HRAS mainly removes organic matter by flocculation and adsorption. It can adsorb and retain the organic matter in the water to the maximum extent and then become the first selected process of 'carbon capture' technology [17](Figure 1). Chen [18] conducted experiments and found that maintaining a low SRT (0.8d) and HRT (1.5h), using HRAS technology. Guven et al. [19] conducted a pilot study on the influent of the sewage treatment plant, and used different HRTs to run the HRAS process. It was found that under the condition of HRT = 60min, the total COD removal rate reached the highest 59 % while minimizing SRT (0.35d), the mineralization rate of adsorbed COD was the lowest (23 %), which greatly improved the 'carbon capture' efficiency. A large number of studies have shown that shorter HRT and SRT are the key to achieving high carbon capture and low biomineralization in HRAS. A pilot study was also carried out in a sewage treatment plant. The COD capture rate of HRAS process reached 87 %, and the COD mineralization rate was only 16 %. Compared with the traditional activated sludge process, the COD recovery rate was greatly improved[20]. In the context of carbon neutrality, HRAS has attracted attention due to its high carbon capture efficiency and low mineralization rate. Based on short HRT and SRT, HRAS can achieve the efficient capacity of back-end energy recovery. At the same time, it can be used in urban sewage treatment plants to significantly reduce the floor area of structures and investment and operation costs, highlighting the advantages of HRAS in urban sewage treatment plants.

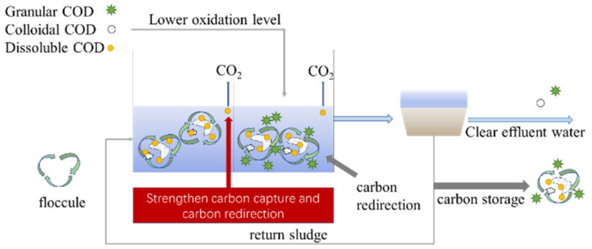

Figure 1 HRAS

(2) CEPT

CEPT removes organic matter in the influent by chemical coagulation, the same as. It was found that CEPT removed more than 60 % of particulate organic matte r[21]. With different coagulants and flocculants, the capture efficiency of CEPT on COD was studied. He et al. [22] used CEPT to treat the influent of the urban sewage plant. It was found that the removal effect of CEPT was the best by adding poly aluminum ferric chloride. The COD effluent was always lower than 60mg/L, and the removal rate reached 74 %. In the San Diego sewage treatment plant, the addition of ferric chloride for CEPT treatment achieved a BOD_5 capture rate of 65 % [23]. In addition, CEPT not only has an excellent organic matter capture rate, but also has advantages in organic matter retention. Budych-Gorzna et al. [24] studied the coagulation and sedimentation of primary sludge by using ferric sulfate and carried it out on-site. Experiments showed that the COD removal rate reaches 70 %. In addition, the application of CEPT increases the easily degradable organic matter in sludge digestion, which is beneficial to energy recovery. Rahman et al. [25] found that the COD capture rate of CEPT was 55 %, and the capture rate was not high, but the COD oxidation rate at this stage was 0, and the organic retention reached 100 %.

(3) Other processes

In addition to HRAS and CEPT, membrane separation processes and micro-sieve processes have also begun to be widely used in 'carbon capture' [21]. For example, a highly loaded membrane bio-reactor (MBR) operated at a very short HRT (0.7h) and SRT (0.5 ~ 1d) can recover 85 % of COD and the mineralization rate is less than 10 % [26]. For example, the anaerobic membrane bioreactor (AnMBR) has a COD removal rate of more than 90 % and a CH4 recovery rate of more than 50 % [27]. The micro-screening process uses a fine filtration device (pore 100μm) to intercept particles, colloids, and soluble COD in the sewage. Compared with the blank group, the total chemical oxygen demand (TCOD) removal rate increased by 43 % to 70 %. Its soluble COD accounted for 82 %, an increase of 27 %. Its biogas production reached 150L / kgCOD, an increase of 13 % [21,28].

Compared with the influent quality of municipal sewage in most European countries, the influent COD of most sewage plants in China is lower, which limits the application of front-end carbon capture in sewage plants. However, there is a concept of front-end carbon source separation that applies to our country. Its principle is to recycle cellulose at the front end. Lignocellulose is complex and stubborn, hindering the biodegradation process [29]. Like filamentous bacteria, some 'bridging' effects of lignocellulose may also cause sludge bulking. The screened cellulose has many uses, such as the manufacture of asphalt additives, soil amendments and biocomposites.

3.2 Energy recycling

Energy recovery and utilization is one of the important conditions for achieving carbon neutrality in sewage treatment plants. It is mainly based on energy recovery technologies such as anaerobic digestion-combined heat and power(AD-CHP) and heat recovery.

(1) Anaerobic digestion-combined heat and power(AD-CHP)

Anaerobic digestion technology captures sludge to produce methane (CH_4), which can extract chemical energy from sludge through cogeneration technology. HRAS and CEPT technologies achieve carbon capture. Solon et al. [30] evaluated the CH_4 production of the traditional activated sludge process and HRAS, and found that the CH_4 production of HRAS was 1.5 times that of the traditional activated sludge process. At the same time, Solon et al. also evaluated CEPT and the traditional activated sludge process, and the CH_4 production of CEPT was 25 % higher than that of the traditional activated sludge process. Rahman et al. [25] also found that the methane production of CEPT was 1.8 times that of the traditional activated sludge process. In addition, the energy recovery efficiency depends not only on the amount of carbon source captured, but also on the CH_4 production efficiency of anaerobic digestion. In this regard, researchers have conducted a lot of research to improve the efficiency of anaerobic digestion CH_4 production. Yu [30] used thermal hydrolysis (90 °C) pretreatment to optimize anaerobic digestion, and the average CH_4 yield was 0.159 m^3/kg VS, which was much higher than that of untreated sludge (0.034 m^3/kg VS). The addition of alkali can reduce the temperature of heat treatment and improve the treatment effect. The CH_4 yield was maintained at 0.55 m^3/kg VS by low-temperature hot alkali (60 °C, pH=12.0) pretreatment [31]. Anaerobic co-digestion of other organic solid wastes and excess sludge can also increase CH_4 yield. He [32] co-digested by adding kitchen waste, and the maximum CH_4 yield was 4.3 times higher than that of sludge anaerobic digestion alone. Fitamo et al. [33] conducted a co-digestion pilot test using kitchen waste, and achieved a CH_4 yield of 425 mL/kg VS at medium temperature (55 °C), which was 48 % higher than that of traditional anaerobic digestion. While increasing the CH_4 yield, it also reduces the treatment dilemma of kitchen waste. The biogas produced by anaerobic digestion produces electricity and heat through cogeneration technology. Electric energy can be used for energy self-sufficiency, and thermal energy can be used to supplement digestion tank heating and building heating.

(2) Heat energy recovery

In addition to chemical energy, heat energy is also a recyclable energy in sewage. According to the estimation of the actual recoverable energy in urban sewage, Hao et al. [34] believed that thermal energy is also an energy that cannot be ignored. The sewage temperature is usually below 30 °C, and the sewage flow rate of the sewage treatment plant is stable and available throughout the year, which makes the cold and heat recovery of this low-grade energy practical. At present, heat energy recovery is mainly carried out by the combination of a water source heat pump and heat exchanger. Water source heat pumps and heat exchangers are actually a kind of heating or cooling system. It uses different temperatures between water and the surrounding atmosphere to transfer heat to the water supply or from water, which can effectively extract heat from the water source. Domestic and foreign sewage treatment plants have practical applications in heat energy recovery. For example, the Norwegian Asker sewage treatment plant maintained 15.5 × $104m^2$ of commercial building heating by using a water source heat pump [35]. A large municipal sewage treatment plant in Beijing (treatment scale of 1 × $104m^3$/d) used a water source heat pump to evaluate the heat recovery. The heat recovery reached 175 GJ at a temperature difference of only 3 °C, which could meet the heating demand of 5 × $104m^2$ buildings [36]. A sewage treatment plant in Qingdao not only realizes its own heating demand through a water source heat pump and heat exchanger, but also meets the heating demand of 20 × $104m^2$ in the surrounding area [37]. The engineering application shows that the recovered medium-temperature heat energy can be used not only for digestion tank heating, sludge dewatering, and winter heating of the whole plant, but also for heating/cooling of the surrounding areas, which is of great significance for reducing the heating energy consumption of sewage treatment plants and regional heating, and indirectly reducing greenhouse gas emissions. At the same time, it should be noted that the heat energy recovery of raw water will make the heat pump easily damaged, and the treated water is more suitable for heat energy recovery, while avoiding the influence of temperature change on the biochemical system.

(3) Power generation with solar energy

In addition to drawing energy from sewage, solar energy is also available in sewage treatment plants. Large-scale urban sewage treatment plants generally cover a wide area, and various structures have a large surface area. This feature provides the basic conditions for the layout of rooftop photovoltaic power generation technology. A photovoltaic power generation system is arranged above the biochemical tank and the secondary sedimentation tank in a sewage treatment plant, which compensates for 20 % of the total power consumption of the plant [38]. Tangwang and Liuwei sewage treatment plants in Yangzhou City use photovoltaic power generation to achieve energy self-sufficiency [39]. In addition, the coverage of photovoltaic panels on structures may also play a role in thermal insulation, further reducing thermal energy consumption. The combination of anaerobic digestion-cogeneration technology, heat energy recovery, and solar energy can maximize energy recovery and achieve energy self-sufficiency while reducing operating consumption.

The photovoltaic power generation system is arranged above the biochemical tank and the secondary sedimentation tank in the water treatment plant.

3.3 Resource recovery

(1) Phosphorus recovery

Phosphorus is an essential element for maintaining life. It has attracted much attention due to its non-renewable nature. It is difficult to meet the growing uptake of phosphorus by human beings if only relying on the natural cycle of phosphorus. Therefore, it is necessary to develop sustainable phosphorus-use methods to curb the disorderly mining of phosphate rock in nature. Based on the concept of sustainable development, the recovery of phosphorus from sewage has gradually attracted the attention of the industry. The efficient recovery of phosphorus can not only alleviate the shortage of global phosphate rock resources and drive the sustainable development of sewage treatment, but also make up for the deficit of energy consumption in the operation of sewage plants and reduce the emission of greenhouse gases. Although LCA can be used to evaluate phosphorus recovery, most studies have only evaluated economic benefits, and few have evaluated environmental benefits. Compared with traditional fertilizer production, a wastewater treatment plant that uses struvite to achieve full phosphorus recovery can offset about 13 000 t CO_2 emissions per year [40,41]. Chai [42] used LCA to calculate greenhouse gas emissions from sewage treatment plants. The results showed that the recovery of phosphorus and other resources from sewage could effectively reduce greenhouse gas emissions by 7 % ~ 18 %. From the perspective of life cycle, nutrient recovery can not only alleviate the consumption of resources such as phosphate ore, but also indirectly retain energy and water. Recycling nutrients will reduce the demand for traditional fossil fertilizers and save energy and water for the production of traditional fertilizers.

There are two main ways of phosphorus recovery: phosphorus recovery from phosphorus-rich aqueous phase and phosphorus recovery from sludge. The phosphorus-rich aqueous phase recovers phosphorus in the form of magnesium ammonium phosphate (MAP). The phosphate concentration at the end of the anaerobic tank and the sludge digestion solution is high, and the recovery potential is huge [43,44]. Sludge incineration is the main way to recover phosphorus from sludge. The incineration ash contains almost all the phosphorus in the treated sewage, so the recovery is not only simple, but also the maximum recovery (up to 90 % of the phosphorus load of the original sewage) [45]. There are three main methods for phosphorus recovery from sludge ash: biological method, wet chemical method, and thermochemical method. Combining phosphorus-rich aqueous phase and sludge to recover phosphorus can meet the needs of sustainable treatment to the greatest extent. Under the goal of carbon neutralization, this method can not only realize the anaerobic digestion capacity of sludge, but also maximize the recovery of potential resources in sewage. There have been engineering cases of phosphorus recovery from sludge. For example, the Amersfoort wastewater treatment plant in the Netherlands can recover 2 000 t struvite per day from phosphorus-rich concentrate and digestive juice. The purity of the recovered struvite particles is as high as 99.9 %, which can be further packaged as high-quality fertilizer for secondary utilization [8]. Under the background of carbon neutrality, recycling resources and energy from sewage plants have become the trend of industry development, which has brought great development opportunities for the phosphorus recovery industry.

(2) Reclaimed water utilization

After the resources in the sewage are recovered, the reuse of the treated sewage can further improve the utilization rate of water resources and economic benefits. Recycling reclaimed water in the fields of farmland irrigation, industrial production, and landscape water use can reduce the carbon footprint and reduce the energy consumption caused by the development of more energy-intensive water resources. In addition, reclaimed water can also be used for groundwater recharge and direct drinking reuse. Groundwater recharge can alleviate the risk of land subsidence and seawater intrusion in coastal areas. It can also eliminate the demand for ground storage facilities and solve problems related to uncovered surface reservoirs, such as water quality deterioration and odor caused by evaporation loss and algae reproduction. Direct drinking reuse refers to the direct introduction of treated sewage into the water distribution system without involvement in storage (pipeline to pipeline). Reclaimed water reuse can save electricity and chemicals needed to supply water from raw water sources, and has great potential to offset carbon footprint [46]. The main methods of realizing water resource regeneration in sewage plants can be divided into coagulation sedimentation and media filtration. Based on the consideration of the safety of reclaimed water, the reclaimed water utilization technology with membrane treatment as the core has become the development trend of sewage plants. The technology of water resource regeneration and reuse in wastewater treatment plants by membrane treatment has been widely used abroad, which is technically and safely feasible. Singapore plans to achieve the goal of carbon neutrality by 2030 through basic equipment transformation and process transformation of reclaimed water plants. The transformation of basic equipment reduces the energy consumption in the operation process by improving the operational efficiency of the equipment in the reclaimed water plant. There are three main methods for process transformation. One is the side-stream Anammox autotrophic denitrification process, and the other is the membrane bioreactor. The third is sludge pretreatment. The side-stream Anammox autotrophic denitrification process can save the carbon source consumption in the denitrification heterotrophic denitrification process and reduce the aeration energy consumption by 3 % ~ 5 %. The use of a membrane bioreactor (MBR) will increase the power consumption by an additional 0.11 kWh/m^3. However, due to the addition of MBR, the downstream advanced processing units such as microfiltration/ultrafiltration (MF/UF) can be eliminated, and the operational energy consumption will be reduced by 15 %. Even the Zhangyi No.2 reclaimed water plant with double membrane technology (reverse osmosis membrane and microfiltration membrane) has reduced the average power consumption during operation to a low level of 0.75 kWh/m^3 through process optimization [47]. Pretreatment of excess sludge for cell wall breaking can increase the amount of methane produced by anaerobic digestion by 10 % [48]. High-quality reclaimed water has broad market demand in the future and is expected to become an important measure to solve the problem of a water shortage caused by water pollution.

(3) Residual temperature heat energy utilization

For cleaning and washing purposes, the water used in the home is heated to a comfortable temperature or even higher. Due to the input of heat, the average temperature of domestic sewage (27 °C) is 2 ~ 17 °C higher than that of the household [49]. The utilization potential of sewage waste heat energy is higher than the contribution rate of chemical energy in sewage to carbon neutralization (the recovery potential of sewage heat energy is 9 times that of chemical energy) [49]. If 6 % of hot water can be saved or 10 % of heat in sewage can be recovered, the total energy consumed in the sewage treatment process can be compensated [50]. The recovery and utilization of organic chemical energy can be fed back to the sewage treatment plant to make up for the energy deficit. On this basis, the utilization of waste heat energy can achieve the ultimate goal of carbon neutralization through heat output exchange [51]. The waste heat energy can not only meet the needs of the factory, but also radiate to the surrounding houses to meet the needs of refrigeration and heating. The research on the centralized utilization of waste heat energy in Europe was earlier. Since the 1980s, several large-scale water source heat pumps with a total heat capacity of more than 1500 MW have been installed in the heating system in Sweden. These heat pumps are used in regional heating systems [52]. The environmental benefits brought by lower CO_2 emissions provide a broad development prospect for the development of water-source heat pumps. Unlike combustibles such as natural gas, coal, and fuel oil, sewage waste heat energy belongs to low-grade energy and cannot be transported long distances without significant energy loss [53]. Therefore, the heat exchanged by the sewage plant through the water source heat pump is used in situ at the user's end. There are two ways of in-situ utilization, one is home form, and the other is pipeline form. It is worth noting that the in-situ utilization will cause serious unit corrosion during operation. Therefore, the heat exchanger should be inspected and repaired regularly to solve the problems of pollution, blockage, and corrosion in time. The heat output of the water source heat pump needs to be consumed by users with large and stable heat demand, so the exchange of heat for sludge thermal drying is a potential choice. The water content of sludge can be reduced from 80 % to 40 % ~ 70 % by using sewage waste heat energy for sludge drying. From the perspective of sustainable development of sewage treatment plants, sludge incineration after drying realizes the conversion of waste heat energy from low-grade energy to high-grade energy. It is of great practical significance to recover heat energy from sewage. Reducing the carbon footprint will be the only way for the development of sewage treatment plants in the future. Through the recovery and utilization of waste heat energy in sewage, more carbon emission reductions will undoubtedly be achieved, to achieve the goal of carbon neutralization operation.

4. Conclusions

The key to achieving the goal of carbon neutrality in wastewater treatment plants is to recycle resources and energy and save energy and reduce the consumption of treatment facilities. At present, China's sewage plants still face some challenges in achieving carbon neutrality, which are mainly divided into the following three aspects: (1) The influent COD of sewage treatment plants in China is generally low, which is seriously limited. (2) In China, less than 3 % of wastewater treatment plants are equipped with anaerobic digestion facilities, and a considerable part of them are in poor operation. (3) Most of the sewage treatment plants in China have a low degree of intelligence and fine control, and it is impossible to adjust the dosage and aeration amount in real-time according to the influent load.

Therefore, the future development direction is mainly the following four aspects: (1) Strengthen the development of low-carbon and resource recoveries and treatment technologies, such as anaerobic ammonia oxidation technology, short-cut nitrification, and denitrification technology, to minimize the overall energy balance of the sewage plant. (2) Improve the level of pipe network construction, improve sewage collection rate and influent COD, strengthen sludge resource disposal, and introduce an exogenous organic matter for anaerobic co-substrate digestion to improve energy recovery efficiency. For example, the use of food waste for anaerobic co-digestion can increase the organic matter content in the digestion process and increase the biogas yield. (3) Make full use of the waste heat energy in sewage, develop efficient heat exchange technology, and promote the development of recycling heat energy. (4) Accelerate the intelligent development and automation process of sewage treatment plants, and realize the transformation of the operation mode of urban sewage treatment plants.

Foreign sewage treatment plants have achieved carbon-neutral operation, which provides a reference for the operation of sewage treatment plants in China. To achieve carbon neutrality, wastewater treatment plants need to efficiently recycle resources and energy to achieve energy self-sufficiency. Resource-based sewage treatment is gradually becoming the theme of the times in the global sewage treatment industry. Although China's sewage plants still face a series of challenges in achieving carbon neutrality, they are also actively exploring ways suitable for their development. The concept of sewage treatment plants has opened a new chapter of sustainable management of sewage and harmonious urban water ecology in China.

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