ISSN: 2710-0588

Greenhouse Gas Emission Accounting Study for Sewage Treatment Plants

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Abstract

Due to the characteristics of consuming a lot of energy and emitting greenhouse gases during the operation of the sewage treatment industry, it has attracted widespread attention in the process of promoting carbon neutrality and carbon emission reduction in China. How to systematically and comprehensively quantify the carbon emission level of urban sewage treatment plants is an important prerequisite for promoting the optimal operation and management of urban sewage treatment plants and formulating emission reduction strategies. Combined with the literature research, this paper takes the operation stage of urban sewage treatment plants as the research object, uses carbon emission accounting methods to analyze the principles and characteristics of carbon from different sources such as direct carbon emissions and indirect carbon emissions, explores their application scenarios and limitations, and puts forward the development trend analysis and suggestions of the research and application of carbon emission accounting methods for sewage treatment, so as to provide reference and reference for the development of new carbon emission assessment technologies in the field of sewage treatment.

Keywords

Sewage Treatment Plants; Carbon Neutral; Accounting Methodology; Carbon Emissions.

1. Background

Carbon neutrality is a consensus strategy for countries worldwide to address climate change. The emission of greenhouse gases has a great impact on the entire ecosystem of the Earth. Mankind has entered the era of global climate change, and effectively coping with global climate change will be a common challenge that mankind needs to face for a long time[1]. Global carbon dioxide emissions are increasing yearly, and the regional climate is very close to the ecological environment on which people depend. In this context, China has announced two major goals of carbon dioxide, to control China's carbon emissions, adjust energy consumption patterns, improve the circulation of the ecological environment, and then support the construction of a community with a shared future for mankind[2].

On October 28, 2021, China's National Liaison Officer for the United Nations Framework Convention on Climate Change (UNFCCC) officially submitted the Progress Report on China's Implementation of Nationally Determined Contributions to the Secretariat of the Convention, reiterating that "carbon emissions will peak before 2030", and that the overall goal of "pre-carbon neutrality" in 2060 is to reduce carbon dioxide emissions per unit of GDP by 65% compared with 2005, the proportion of non-fossil energy in primary energy to reach 25%, and forest resources to increase by 6 billion cubic meters compared with 2005. The total number of photovoltaic power stations increased by 6 billion cubic meters, with an installed capacity of 1.2 billion kilowatts[3]. According to the above data report, China's carbon emission issue has become a hot topic.

ISSN: 2710-0588

"Carbon emission peaking" refers to the point at which the CO2 emissions of various entities, including the world, countries, and cities, continue to increase and peak, and then begin to show an overall downward trend. So far, compared with developed countries, many countries have achieved the goal of "peaking carbon emissions", and carbon emissions are declining. The goal of "carbon peak and carbon neutrality" proposed by China in the implementation of green development is of great significance. First of all, this is China's positive response to the concept of sustainable development, a good way to deal with climate change, an important step to achieving clear waters and lush mountains, and it is also an important step for China to demonstrate its international commitments, assume historical responsibilities, and promote the development of the world in the direction of ecological and low-carbon.

The focus is often on carbon emissions from buildings, transportation, and power plants, but wastewater treatment plants are also a high-carbon industry, with the main greenhouse gases CO2, N2O, and CH4 emitted. Wastewater treatment plants are large consumers of energy and a significant source of greenhouse gas emissions. Sun Qiangqiang inspected the carbon emissions of urban sewage treatment plants in 2021 as 0.02×104~11.98×104t, of which electricity consumption carbon emissions are the main source of carbon emissions, accounting for 62.6%~98.9% and 79.7% overall, and the carbon emission intensity of sewage plants is 0.168~1.070 kg·m-3, with an average value of 0.326 kg·m-3, and most of them are lower than the intensity values in other parts of the country. Wang Shuo et al found that the carbon emissions of the sewage treatment system in Suzhou from 2001 to 2020 were 43,066,082 tons of CO2-eq, with CO2 as the main contributor and the carbon emission factor of 1.3687~1.9499kgCO2-eq/m3. Reducing CO2 emissions from wastewater treatment processes and N2O emissions from sludge disposal processes is the most critical approach to carbon reduction. Qiu et al. found that the average carbon emission intensity of 20 wastewater treatment plants was (0.87±0.22) kgCO2/m3, of which electricity consumption, chemicals, and direct N2O emissions contributed about 40%, 23%, and 30%, respectively. Liu Yueting et al. showed that chemical consumption and electricity consumption are the main sources of carbon emissions in sewage treatment units, while CH4 and N2O directly discharged by sludge disposal units account for a large proportion. The establishment of a comprehensive evaluation model suitable for sewage treatment plants is an important tool for carbon neutrality analysis of wastewater treatment resource utilization.

2. Research on Carbon Emissions from Sewage Treatment at Home and Abroad

Urban sewage treatment is a high-energy-consuming industry, and greenhouse gases such as CO2, CH4, N2O, etc., will inevitably be produced in the whole process of sewage treatment. In 2021, the sewage treatment capacity of China's urban sewage treatment plants was 2.1x10m3d-1, and the sewage treatment rate reached 97.89%.

Sewage treatment is a typical energy-intensive industry, In the United States and other developed countries for water and sewage treatment electricity accounted for 3-4% of the electricity consumption of the whole society, and the average energy consumption of sewage treatment in China is 0.29-4kW.h/m3, energy costs up to 40% ~ 80% of the total operating cost. Sewage treatment refers to the process of purifying sewage, reducing pollutant concentration or eliminating pollution, and making sewage meet discharge standards by physical, chemical, biological, and other means. The process can generally be divided into three stages: pre-treatment, biochemical treatment, and advanced treatment. According to the treatment process of the sewage treatment plant and its impact on CH4 emissions, Cai Bofeng et al. divided the process into aerobic, anaerobic, and abiotic, and established the weighted CH4 emission factor of each province based on the COD removal ratio of the sewage treatment process in different

ISSN: 2710-0588

provinces. Statistics from the Ministry of Housing and Urban-Rural Development show that from 2016 to 2021, the total amount of rural sewage discharge in China continued to increase, and the total sewage discharge reached 35 billion m3 in 2021. According to the relevant research results of the Ministry of Ecology and Environment, in 2021, the domestic sewage discharge of rural residents in China will be about 21.754 billion cubic meters, which is 60.59% of that of urban areas, while the per capita discharge is less than 1/2 of that of urban residents[4]. Biological nutrient removal (BNR) is being used in more and more countries around the world to protect the local water environment, and as wastewater treatment processes move from simple to complex, the demand for energy, often in the form of electricity, is fed into the wastewater treatment system. For example, in the pretreatment stage, the electricity consumption of raw sewage collection and extraction is about 0.02-0.1 kWh/m3 (Canada), 0.045-0.14 kWh/m3 (Hungary) and 0.1-0.37kWh/m3 (Australia) The traditional activated sludge method consumes 0.46 kWh/m3 (Canada), 0.269 kWh/m3 (China), 0.33~0.6 kWh/m3 (United States) and 0.3~1.89 kWh/m3 (Japan).)。 Li Xiangwei [5]et al. analyzed four samples in Daihai, a eutrophicated salt lake in Inner Mongolia, to investigate carbon dioxide (CO2) and methane (CH4) emissions. Yao Yao et al[6] proposed a bottom-up carbon emission prediction framework based on cadastral plot size based on Vector Cellular Automata (CarbonVCA) by integrating land use modeling and carbon emission estimation. Kacprzak[7] described 34 wastewater treatment plants that generate about 700% of the total electricity of about 337 GWh from biogas in Poland. The biogas power generation potential of Poland wastewater treatment plants is estimated to be around 850-25 GWh per year, and according to the Poland Statistics Bureau in Poland, about 100% of the sewage sludge is directly used for agriculture and land reclamation. The Hossein [8] study focused on the worst-case scenario of this jet dilution and mixing: vertical dense sewage discharge, no ambient current, and in shallow water, the jet hits the water's surface. Hongwei Liu et al[9] considered the characteristics of carbon emissions in the hidden stage, determined the calculation range of carbon emissions, and used the carbon emission factor method to calculate the carbon emissions in the hidden stage. At the same time, it is proposed to promote the life cycle of buildings, consider the impact of design optimization on carbon emissions, establish a rating system for low-emission buildings, and consider the comprehensive impact of single and multiple factors. Scholars such as Ghorbani Bahram[10] take advantage of the significant increase in global energy demand and greenhouse gas emissions and the need to develop methods for the efficient and reliable extraction of sustainable carbon-neutral energy. The Carmen Teodosiu[11] study focused on the environmental assessment of municipal wastewater treatment plant (MWWTP) discharges through these three assessment methods, to understand their (methodological) weaknesses and strengths in capturing impacts. Using the dynamic relationship between sewage discharge and urbanization, Emilia Németh-Durkó[12] found that electricity consumption is positively correlated with carbon emissions, meaning that the number of cities increases emissions.

3. Carbon Emission Accounting Methods

3.1. Emission Factor Method

At present, the commonly used carbon accounting methods for sewage plants include the emission factor method, the whole life cycle method, the material balance algorithm, and other methods, which are suitable for different scenarios. The accounting method, the data are accurate, the quality is ranked> the measured method> the whole life cycle method> the emission factor method [39]. In general, the emission factor approach is often used due to the difficulty of obtaining high-quality data. The emission factor method uses the statistical average of gas emissions per unit of product output. Therefore, the emission factors vary greatly due to factors such as different technical levels, production conditions, and energy consumption.

ISSN: 2710-0588

Carbon emissions are collected and managed by regulators, and it is becoming increasingly difficult to obtain data on activity emissions. When calculating CO2 emission factors, it is necessary to take into account differences due to region, time, etc., in real-time. The emission factor method is the first method proposed by the IPCC to estimate carbon dioxide emissions. The basic idea is to construct an active CO2 emissions inventory based on the emission source. CO2 emissions were estimated by multiplying AD by the emission factor EF using activity data.

3.2. Mass Balance Method

The mass balance method (MBA) is one of the main methods for the key comparison of pure substances in the International Bureau of Weights and Measures (BIPM-OAWG), and is used as the benchmark method for purity determination in CCQM-K55C: L-amino acid purity testing, CCQM-P20E theophylline purity testing [40] and other international comparison projects of pure substances. The mass balance legal value has high accuracy and low uncertainty and is widely used in the purity determination of reference materials. However, this method requires the use of multiple instruments in the valuation process, and it is difficult to isolate some trace impurities and thus accurately quantify them, resulting in a large workload and a cumbersome determination process [41]. The mass balance method is suitable for calculating the emission reduction of CO2 gas emissions in sewage treatment plants in a certain period and is used to guide the carbon emission reduction practice of sewage treatment plants [42]. The wastewater treatment plant only needs to substitute the basic data to obtain the CO2 emission reduction of the treatment and disposal process currently used by the wastewater treatment plant.

Typical impurities in the mass balance method include (1) structure-related impurities; (2) water impurities; (3) non-volatile impurities; and (4) Solvent residue.

3.3. Measured Method

The actual measurement method usually uses monitoring methods and continuous measuring devices approved by the national authorities to measure, flow and emission gas concentrations, and calculate total emission statistics based on the measured data. The actual measurement method has certain limitations when sampling environmental factors. If the collected sample is not representative, the measurement results may not be accurately analyzed. At the same time, the actual measurement method also puts forward high professional requirements for samplers, which is not suitable for some industrial applications. The National Climate Change Plan (2014-2020) issued by the State Council requires: Improve the emission measurement system, strengthening measurement and data quality monitoring, and ensuring that the data is true and accurate.

4. Carbon Emission Accounting of Sewage Treatment Process

There are many wastewater treatment processes, including A2O, oxidation ditch, MBR, biofilm reactor, AO, etc., but no matter what kind of treatment process, the wastewater treatment process can be roughly summarized as wastewater enters the wastewater collection system and enters the wastewater collection system. The municipal pipe network of the treatment plant first enters the pretreatment unit, which usually includes a coarse screen, a lifting pump, a fine screen, a sand chamber, etc., and then enters the biological treatment unit, which usually includes an anaerobic tank, after anaerobic tank treatment and aerobic tank treatment, and finally enters the advanced treatment unit, which usually includes sedimentation, sand counting, reverse osmosis, etc. Once the wastewater has reached the appropriate standards, it is recycled or discharged into a nearby water system.

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4.1. Direct Carbon Emissions

Direct emissions of greenhouse gases from wastewater plants, i.e. CO_2, N_2O, and CH_4 gases are emitted directly into the atmosphere during the treatment of sewage or sludge, such as CO_2 from the degradation of organic matter in the sewage biological treatment unit, CH_4 from the anaerobic digestion of sludge or other sludge disposal processes, or N_2O from the denitrification process of wastewater.

The CO_2 emissions generated during the sewage treatment process of urban sewage treatment plants are calculated using the emission factor method. CO_2 emissions are determined based on the reduction of COD (chemical oxygen demand) during the inlet and outlet of wastewater. When studying the CO_2 emissions from wastewater treatment, the vast majority of researchers adopt the IPCC accounting method, which regards the CO_2 directly emitted in the wastewater treatment process as the source carbon, and does not consider the method and direction of CO_2 research, and the measurement data is less, or even less. The study concluded that there is a correlation between CO_2 emissions and COD reductions, which means that the wastewater treatment process reduces the CO_2 emission factor. Chen Shilong [44] studied the emission characteristics of carbon dioxide under the UCT process. Xie Qingjie et al. [45] studied the CO_2 emission characteristics of wastewater treatment under the CAST process. Jiang Libing et al. [46] summarized the CO_2 emission pathways and detection methods of urban sewage treatment plants at home and abroad: the CO_2 emission intensity is also different due to different treatment processes; Xie et al. [37] also studied the CO_2 emission characteristics of wastewater treatment plants under the Bailek process. Bao et almeasured CO_2 and influent and effluent COD data in two wastewater treatment plants using the AO wastewater treatment process, and obtained EF_{CO2}/COD of 0.68 kg CO_2/kg COD and 0.46 kg CO_2/kg COD, respectively, and the EF_{CO2}/COD used in this paper was the average value of the two, which was 0.57 kg CO_2/kg COD. In the process of sewage treatment, the organic matter contained in it is digested and degraded and the internal wastewater treatment process will produce CH_4 emission due to digestion, degradation, and endogenous respiration. The emission coefficient method was used to estimate and calculate the CH_4 emission generated in the sewage treatment process of urban sewage treatment plants in China, and the CH_4 emission was determined according to the reduction of COD (chemical oxygen demand) in the process of sewage import and export.

4.2. Indirect Carbon Emissions

The indirect emission of greenhouse gases from sewage treatment plants refers to the potential carbon emissions caused by the consumption of other forms of energy, such as the carbon emissions of electricity and heat consumption by sewage plants will be reflected in the form of power generation and fossil fuel combustion, and the materials consumed by sewage plants, such as carbon sources and flocculants, will also produce certain carbon emissions in their pharmaceutical processes.

In municipal and domestic wastewater treatment plants, the degradation of organic matter cannot rely solely on the equipment itself, the aerobic and anaerobic reactions of the wastewater, and the biological respiration inside. It must also be supplemented by other chemical reactions to achieve the purpose of COD removal and non-toxicity. To achieve the purpose of nitrogen and phosphorus removal. In this case, various chemicals need to be put into the process. For example, due to the low organic content of the wastewater, the pH of the wastewater can be adjusted by adding carbon sources such as glucose and methanol or a composite carbon source and lime. Polymer sulfide added during wastewater desulfurization, materials added in the aerobic stage of wastewater, defoamer, hypochlorous acid disinfectant added in wastewater disinfection stage, etc. The production, transportation, and placement of these chemicals all require energy, resulting in indirect CO_2 emissions. At present, China's

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energy power generation mode is mainly thermal power generation, supplemented by nuclear power, wind power, hydropower, solar power generation, and other clean energy power generation.

Energy consumption includes the consumption of electricity and heat, that is, the electricity and heat purchased in the process of production and operation of sewage treatment plants, excluding the use of office and residential buildings. Electricity and heat are converted into standard coal, and the CO2 emission factor of standard coal is used to calculate the indirect emissions from energy consumption.

Material consumption refers to the coagulants, flocculants, carbon sources, disinfectants, cleaning agents, and other chemicals consumed in the production and operation of sewage treatment plants. In general, depending on the type of substance consumed, the mass of consumption is multiplied by the emission factor, and then the CO2 emissions corresponding to all the substance consumption are added together to obtain the indirect emissions of the substance consumed.

5. Research Objectives

The sewage treatment plant is one of the industries with high energy consumption and high carbon emissions, and scholars from all over the world have established a variety of carbon emission calculation models for sewage treatment plants, at the same time, they have also realized that there is a considerable potential energy in sewage treatment plants, and through reasonable and effective energy recovery processes, the resources and energy that have been ignored in the past can be used to make up for the carbon emissions of sewage plants. Carbon dioxide emitted by wastewater treatment plants is an indirect pollutant that cannot be ignored in the wastewater treatment process. Due to its strong greenhouse effect and ability to damage the environment, it is necessary to fully understand its generation and accumulation to achieve carbon-neutral operation of wastewater treatment plants. Then, the corresponding technical strategies to reduce carbon dioxide emissions are proposed. At present, there are few studies on the CO2 generation process of sewage and traditional sludge treatment systems using models, simulating the CO2 generation and treatment of sewage plants, and accounting for the gas generated.

6. Research Content

According to the sewage treatment technology and the traditional sludge treatment process, the CO2 carbon emission model was constructed to understand the advantages of carbon emission in the sewage treatment process through comparison. According to the relevant policies, inventory specifications, and domestic and foreign research on carbon emissions from sewage treatment, the carbon emission accounting methods in this paper include the emission factor method, mass balance method, model method, and measurement method to test the greenhouse gases CO2, CH4 and N2O generated by direct emissions, and the greenhouse gas CO2 generated by indirect emissions such as carbon sources, chemicals, electricity consumption, and heat energy. The above model construction is verified through case analysis, and carbon emission accounting is carried out according to the COD (chemical oxygen demand) and TN (total nitrogen) data obtained from the monitoring during its actual operation, and the possibility of achieving carbon neutrality and the results of energy saving and consumption reduction (unit energy consumption) are studied. The carbon emission accounting of the sample sewage plant was carried out, the carbon emission level was discussed, and the energy recovery process was proposed to evaluate the carbon-neutral operation potential of the sewage plant.

ISSN: 2710-0588

7. Implications of the Study

(1) It will help the sewage treatment plant to achieve the "double carbon" goal as soon as possible under the condition of ensuring that the sewage water quality meets the discharge standards, to protect the ecological environment.

(2) It will help to actively respond to China's concept of sustainable development, a good prescription for climate change, and an important policy to achieve lucid waters and lush mountains.

(3) It will help to comprehensively evaluate the current situation and future development trends of carbon dioxide emissions in China's sewage treatment industry. It will not only provide an important reference for planning the development of the sewage treatment industry but also be of great significance for evaluating the future development trend of China's sewage treatment industry. The calculation results of this model make the carbon emission level of each process unit in the treatment process of the sewage treatment plant more intuitive, which makes it convenient to identify the high carbon emission units and their main carbon emission sources, and can provide suggestions for the upgrading and transformation of the sewage treatment plant.

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