International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 739

ANALYSIS OF THE EMISSION REDUCTION EFFECT OF SEWAGE TREATMENT DURING THE CONSTRUCTION OF A SPONGE CITY IN XIAMEN

Weiwei Shao[1], Yuanfei Li[2], Jiahong Liu[1,]*, Zhiyong Yang[1], Zhaohui Yang[1], Yingdong Yu[1], Penggui Xie[3]

1 State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China

2 Liaoning Normal University, Dalian 116029, China

3 Xiamen Urban Planning & Design Institute, Xiamen 361012, China

ABSTRACT

Climate change caused by increased greenhouse gases (GHGs) is having an increasingly profound impact on human society. Urban sewage treatment processes and tailwater pollutant emissions generate large amounts of carbon dioxide, methane, and nitrous oxide, which are considered important anthropogenic GHGs. Based on the emission factor method recommended by the IPCC (Intergovernmental Panel on Climate Change) this study analyzed the carbon dioxide equivalent (CO_{2e}) of wastewater treatment in Xiamen in 2016 and the emission reduction effect of the development of wastewater treatment for tailwater pollutants after the completion of the sponge city in 2030. The results showed that the CO_{2e} of sewage treatment in Xiamen in 2016 was 71,366,300 t, of which direct carbon emissions comprised 29,200 t and energy consumption and indirect carbon emissions from flocculants comprised 71,337,100 t. In 2016, the amount of GHGs directly generated from the discharge of sewage tailwater pollutants was effectively reduced by 34.11%. Under the same sewage discharge in 2030, compared with the traditional model before the upgrade, the construction of sponge city can effectively reduce carbon emissions by 27.12%, and the emission reduction effect would be significant.

Keywords: greenhouse gas, sewage treatment, sponge city, carbon emission reduction, climate change

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
Symbols	
n	Year

1. INTRODUCTION

Carbon emissions are the general term for greenhouse gas (GHG) emissions. GHGs are gases in the atmosphere that absorb and re-emit the solar radiation reflected from the Earth's surface. The re-reflection of newly emitted radiation back to the ground results in little loss of surface heat. If the process is too intense, then it will cause the greenhouse effect. Research shows that human activities are the main cause of the continuous increase in GHGs such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) in the atmosphere [1].

With the increasing concentration of atmospheric GHGs and the increasing greenhouse effect, natural disasters such as global warming, ecological environmental degradation, and extreme weather are caused [2]. The need to reduce GHG emissions and control climate change is the consensus of the international community. Most industries are conducting carbon emission assessment research and formulating carbon emission reduction countermeasures. Although the sewage treatment industry is a small industry in the national economy, compared with high energy-consuming industries, the GHG emissions of sewage treatment systems are relatively small, but the amount of sewage is large; thus, the GHGs generated by sewage treatment cannot be ignored [3]. With the continuous increase in the urbanization rate, sewage treatment rate, and treatment technology, indirect carbon emissions will increase with the increase in sewage treatment power consumption [4]. At the same time, most of the sludge is simply dewatered and discarded, thereby introducing the

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

environmental risks of re-polluting the water body, producing odor, breeding mosquitoes and flies, and releasing a large amount of CH_4 to the environment. Its greenhouse effect is dozens of times greater than that of CO_2 [5].

With the rapid growth in the population and economy in Xiamen, the discharge of domestic sewage and industrial wastewater has also increased. In 2016, the actual sewage treatment scale of the Xiamen Sewage Treatment Plant was 806,000 t/d, and the tailwater of each sewage treatment plant met the requirements of the first-class B standard. The total scale of the sewage regeneration treatment facilities was 142,000 t/d, and the designed effluent quality met the first-class A standard. As one of the first sponge cities in China, Xiamen has been adjusted, supplemented, and optimized in terms of sewage volume, treatment standards, and facilities layout. The requirements of the treatment grade for retaining and adding tailwater discharge from sewage treatment plants have been clarified, and corresponding small sewage regeneration treatment stations have been set up according to the needs of decentralized sewage treatment to treat local sewage thoroughly. It can be reused in situ as reclaimed water. This study intended to provide theoretical guidance for regional carbon emission reduction by analyzing the total carbon emissions from sewage treatment in Xiamen in 2016 and the carbon emission reduction from tailwater after the sponge city was upgraded.

2. MATERIAL AND METHODS

2.1 Data sources

Data on total sewage treatment, chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) removal in the city of Xiamen were obtained from Xiamen Water Group Co., Ltd. Data on the influent and effluent concentrations of COD and NH_3-N were taken from Xiamen Sponge City Special Planning Report. The sewage discharge standards were based on the "Emission Standards for Pollutants in Urban Sewage Treatment Plants (GB 18918-2002)" and "Environmental Quality Standards for Surface Water (GB 3838-2002)."

2.2 Research boundaries and evaluation indicators

Carbon emissions from sewage treatment are generally divided into direct and indirect emissions. The direct emissions mainly come from CO_2, CH_4, and N_2O directly discharged into the atmosphere during the sewage treatment process. In the IPCC Recommended Methodology Guidelines, the direct emissions of CO_2 are biogenic and not included in the total carbon emissions [6], and they were not considered in this study. Indirect discharge includes the energy consumption of the sewage treatment plant and chemical consumption of sewage treatment. The GHGs produced by the discharge of sewage tailwater pollutants before and after the construction of the sponge city in this study were mainly derived from CH_4 and N_2O.

2.3 Carbon emission estimation method

The GHG emissions from sewage treatment were estimated by the emission factor method. Since the data of the sewage treatment department (COD, NH_3-N removal, etc.) is relatively reliable, the emission factor becomes a key link in determining the carbon emissions of the sewage treatment department. The research on the emission factors of the sewage treatment process in China and the provinces is relatively weak. Currently, it is mainly based on the default emission factors of IPCC. However, the default emission factors of IPCC are mainly from expert experience, mainly based on the operation of sewage treatment plants in developed countries. Its default emission factor is a high estimate for China [7]. In addition, new production processes and technologies have been emerging since 2006, which bring new emission characteristics and need to be reflected in the preparation of national inventories. However, in view of the fact that the main content and insights of 2019 refinements to IPCC 2006 Guidelines has not yet been published [8], the emission factors in this study take into account regional and technological impacts. Finally, based on the global warming potential (GWP) of the Kyoto Protocol over a period of more than 100 y, the GHGs were unified into CO_2 equivalent (CO_{2e}).

2.3.1 CH_4 emissions

The main factor that determines the CH_4 production potential in wastewater is the amount of degradable organic materials in the wastewater. The common parameters used to measure the organic composition of wastewater are biochemical oxygen demand (BOD) or COD. The calculation method of CH_4 produced in the wastewater treatment process is as follows:

$$E_{CH_4} = \left(TOW \times EF_{CH_4}\right) - R_0 \quad (1)$$

$$EF_{CH_4} = B_0 \times MCF \quad (2)$$

In the formula, E_{CH_4} is the total amount of CH_4 discharged in 2016, TOW is the organic matter content in the calculated year, EF_{CH_4} is the discharging factor, R_0 is the amount of CH_4 recovered in the calculated year, B_0 is the maximum CH_4 production capacity and MCF is the CH_4 correction factor . The emission factor of unclaimed CH_4 recommended by IPCC is close to the maximum CH_4 production capacity Bo (0.25kg CH_4/kg COD), but it is difficult to achieve the maximum CH_4 production condition in practice. In this study, the recommended CH_4 emission factor of Fujian Sewage Treatment Plant was calculated based on the detailed and reliable national wastewater treatment plant data by the Environmental Planning Institute of the Ministry of Environmental Protection [7].

2.3.2 N_2O emissions

The calculation method of N_2O produced in the sewage treatment process is as follows:

$$E_{\mathrm{N_2O}} = TN \times EF_{\mathrm{N_2O}} \times 44/28 \tag{3}$$

In the formula, $E_{\mathrm{N_2O}}$ is the annual discharge of N_2O, TN is the removal of nitrogen from sewage, and $EF_{\mathrm{N_2O}}$ is the emission factor of N_2O from sewage. It is taken from the recommended value in the "Provincial Guidelines for the Compilation of Greenhouse Gas Inventories" [9], which is 0.005kg N_2O/kg N. 44/28 is the conversion coefficient of kg N_2O-N to kg N_2O.

2.3.3 Carbon emissions converted from electricity consumption

The indirect emissions of energy consumption can be converted into carbon emissions based on the electricity consumption of the wastewater treatment plant combined with the CO_2 emission factor per kilowatt hour of electricity. The marginal emission factor of electricity is 0.8112 tCO_2/MW h, which is derived from the data of East China, Xiamen belongs to, in China Regional Power Grid Baseline Emission Factor.

2.3.4 Carbon emissions from flocculants

The carbon emissions caused by polyacrylamide (PAM) consumption were calculated based on the consumption of PAM and the corresponding emission factor. The carbon emission coefficient of PAM consumption was 25 kg CO_2/kg [10].

3. RESULTS AND DISCUSSION

3.1 *Carbon emission assessment of sewage treatment plants*

The calculation results of CO_{2e} in the Xiamen sewage treatment industry in 2016 are shown in Table 1. According to the table, the CO_{2e} of the sewage treatment industry in 2016 was 71.37 million t, of which the direct emissions of CH_4 were 692.37 t. According to the GWP, the CO_{2e} emissions were 14,500 t and the direct emissions of N_2O were 49.80 t. According to the GWP, the corresponding CO_{2e} was 14,741 t. The direct emissions of GHGs accounted for a small proportion of the CO_{2e} in the sewage treatment industry.

The CO_{2e} of the indirect emissions of energy consumption and flocculant consumption was 71.34 million t. In 2016, the sewage treatment industry in Xiamen had a total sewage treatment volume of 303.18 million t. As the urban sewage treatment plant electricity consumption is maintained at 0.29kWh/m^3 [11]and the total energy consumption was 87.92 million kWh. PAM was used as a coagulant, flocculant, and sludge dehydrating agent in water treatment. The consumption of the sludge dewatering agent produced 152,000 t of CO_{2e}.

Table 1 Carbon dioxide emission equivalent (CO_{2e}) of the sewage treatment industry in Xiamen in 2016 (10,000 t)

Type	CO_{2e}
Methane (CH_4)	1.45
Nitrous oxide (N_2O)	1.47
Energy consumption	7133.71
Polyacrylamide (PAM)	1.52
Total	7136.63

3.2 *Carbon emission reduction effect of sewage tailwater discharge after the construction of the sponge city*

In 2016, the discharge of COD and ammonia nitrogen in Xiamen sewage treatment tailwater and the direct discharge of sewage into rivers were 38,043.6 t and 4,705.6 t, respectively. The original centralized municipal sewage treatment plant is to be rebuilt, expanded, and revamped in 2030. The discharge standard of tailwater will be upgraded from Grade B to Grade A, and the discharge standard of the new sewage treatment plant will be upgraded from Grade A to the surface water class IV. The water quality of the sewage tailwater is shown in Table 2. Accordingly, in 2030, the discharges of COD and ammonia nitrogen will be 28,084.5 t and 2,479.5 t, respectively. Compared with the values in 2016, the reduction in COD and ammonia nitrogen will be 9,959.1 t and 2,226.2 t, respectively. The corresponding reduction in the CO_{2e} of CH_4 and N_2O will be 9,953.22 t, which was compared with the carbon emissions of sewage tailwater before the upgrade. The amount of wastewater would be reduced by 34.11%. Without the improvement in the sponge city and pollution prevention and control, tailwater from renovation, expansion, and new centralized municipal wastewater treatment plants will still be discharged according to the current level B standard, and the effluent from all existing and newly built small wastewater reclamation facilities will be discharged according to the current level A standard. Under the same sewage discharge levels in 2030, COD and ammonia emissions will reach 34,806.5 t and 4,496.1 t, respectively. Compared with the traditional model, the reduction of sponge city in COD and ammonia emissions could reach 6,722 t and 2,016.6 t in 2030, respectively. The corresponding reduction in the CO_{2e} of CH_4 and N_2O will be 7,911.68 t, and the carbon emissions will be reduced by 27.12%. In addition, sponge parks and green spaces, constructed wetlands, and roof greening have prominent ecological value, and play a significant role in regulating the local climate, mitigating the urban heat island effect, reducing carbon emissions, and improving the urban ecological environment.

Table 2 Water quality of sewage tailwater discharge (mg/L)

	COD_{cr}	NH_3-N	SS	TP
GB 18918-2002 Level 1 B effluent quality	60	8	20	1
GB 18918-2002 Level 1 A effluent quality	50	5	10	0.5
GB3838-2002 Surface water class V	40	2		0.4
GB3838-2002 Surface water class IV	30	1.5		0.3

4. CONCLUSIONS

Based on the emission factor method, this study analyzed the CO_{2e} of wastewater treatment in Xiamen in 2016 and the emission reduction effect of traditional development on the discharge of sewage tailwater pollutants after the completion of the sponge city in 2030. The conclusions were as follows:

(1) In 2016, the CO_{2e} of the sewage treatment industry was 71.37 million t, of which the GHG CO_{2e} directly discharged into the atmosphere was 29,200 t. The energy consumption of indirect discharge and the consumption of flocculants resulted in 71.34 million t of CO_{2e}. There is large potential for energy saving and consumption reduction in sewage treatment plants.

(2) After the completion of the sponge city in 2030, compared with the traditional development before the increase in the standard in 2016, the carbon emissions of sewage tailwater could be reduced by 34.11%.

(3) In the case of the same sewage discharge in 2030, compared with the traditional model, the reduction of COD in the sponge city can reach 6,722 t and that of ammonia nitrogen emission can reach 2,016.6 t, thereby corresponding to the reduction in the CO_{2e} of CH_4 and N_2O by 7,911.68 t and reduction in carbon emissions by 27.12%.

Since the data of the sewage treatment department (COD, NH_3-N removal, etc.) is relatively reliable, the emission factor becomes a key link in determining the carbon emissions of the sewage treatment department. In the past, the research was mainly based on the default values recommended by the IPCC. Due to the continuous emergence of new processes and technologies, new emission characteristics were presented. The emission factors of this study take into account regional and process effects and improve the accuracy of the calculation to some extent. This study only analyzed the GHG emissions from the tailwater pollutant discharge in relation to carbon emission reduction, and did not analyze the carbon emission reduction effect in the sewage treatment process after the sewage treatment plant was upgraded. Thus, there may have been some limitations.

ACKNOWLEDGEMENT

This research has been financially supported by the National Key Research and Development Program of China (2018YFC1508203), the Chinese National Key Research and Development Program (2016YFC0401401), the Chinese National Natural Science Foundation (No. 51739011), and the Research Fund of the China Institute of Water Resources and Hydropower Research (No. 2017ZY02, No. WR0145B502016).

REFERENCE

[1] Li H M. Current research status of greenhouse gas emission estimation for urban sewage treatment [C]. 2013 Annual Meeting of the Chinese Society of Environmental Sciences.
[2] Elfadel M , Massoud M . Methane emissions from wastewater management[J]. Environmental Pollution, 2001, 114(2):177-185.
[3] Barber W P F . Influence of anaerobic digestion on the carbon footprint of various sewage sludge treatment options[J]. Water & Environment Journal, 2010, 23(3):170-179.

[4] Liu H T, Chen T B, Gao D, et al. Comparison of carbon emissions from sludge treatment and disposal processes in urban sewage plants [J]. China Construction Information (Water Industry Market), 2010 (9): 40-41.

[5] Wang H C. Carbon Emission Reduction Path and Potential of Urban Sewage Treatment Industry in China [J]. Water Supply and Drainage, 2017 (3).

[6] IPCC. National for Greenhouse Gas Inventories Programme. 2006 IPCC guidelines for national greenhouse gas inventories, chapter 6 [M]. Japan: IGES,2006:6-27.

[7] Cai B F, Gao Q X, Li Z H, et al. Study on Methane Emission Factors of Urban Wastewater Treatment Plants in China[J]. Chinese Journal of Population, Resources and Environment, 2015, 25(4): 118-124.

[8] Zhu S L, Cai B F, Zhu J H, et al. The main content and insights of 2019 refinements to IPCC 2006 Guidelines[J]. Progress in Climate Change Research, 2018.

[9] China Development and Reform Commission. Provincial Guidelines for the Compilation of Greenhouse Gas Inventories [R]. Beijing, 2011.84-105.

[10] Wang X S, Song L, Bai R Y, Hohhot Area Sewage Treatment Plant Energy Consumption Assessment and Carbon Emission Analysis [J]. Environmental Science and Technology, v.36 (02): 196-199.

[11] Yin Z H, Liu F, Wang Z M, et al. Analysis of Typical Energy Saving Technology in Sewage Treatment Plants[J]. Architecture Science, 2016(12).