Study on Carbon Emission from Sludge Drying and Incineration Process

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Abstract: In China, there is a lack of research on the carbon footprint of sludge treatment and disposal. This paper studied the carbon emissions during sludge drying and incineration process In order to make the research more practical, the carbon footprint of “ZhuYuan sludge incineration project” is calculated by the actual measurement method and model estimation method. Using the model estimation method, the discharge equivalent of CO_2 in the sludge incineration process is 1546.6~1709.9 kg CO_2/t DS; Using the actual measurement method, the discharge equivalent of CO_2 in the sludge incineration process is 3046.6 kg CO_2/t DS. The causes of the difference between the two methods were discussed. Finally, the optimization strategy of reducing the carbon emission of the sludge drying and incineration process is put forward.

1 INTRODUCTION

It is estimated that by 2020, the amount of municipal sludge will reach 6000~9000 million tons. The cost of sludge disposal accounts for about half of the total cost of sewage treatment. Sludge disposal and management is one of the major challenges for the global water industry (Zhou et al., 2013). The sludge treatment process during sewage treatment has become a major source of carbon emissions due to its energy consumption and greenhouse gas emissions. The carbon footprint is a new parameter for the evaluation of the sludge technology route, which reflects the possible greenhouse gases and related climate changes that may be discharged during the process of sludge treatment and disposal (Brown et al., 2010).

In recent years, sludge drying and incineration technology has shown explosive growth in China, especially for some large cities with limited land use. During the "13th Five-Year" period, all the new construction projects of sludge treatment facilities in the three major areas of Shanghai central urban area were dry chemical incineration technology.

Sludge drying is designed to remove or reduce the water content in the sludge. The removal process is divided into two stages, namely, the vaporization and evaporation process on the surface of the sludge and the diffusion process of the water in the sludge. It can reduce the sludge greatly, improve the sludge calorific value, kill the harmful components and create conditions for the utilization of resources.

Incineration is a complete combustion process, especially suitable for large cities that are faced with land restrictions. During the incineration process, the combustible components in the sludge are rapidly oxidized. The temperature required for complete combustion is generally 760~820 ℃. One of the main parameters of sludge incineration is the water content of sludge. The sludge with solid ratio of 30%~50% could combustion without auxiliary fuel. The sludge with solid ratio of 20%~30% needed to add auxiliary fuel and pre-drying in the incinerator. In addition, the low solid content will lead to the increase of the flue gas treatment. Therefore, proper solid ratio should be selected before incineration. Another important parameter of sludge is the sludge calorific value (Cao and Pawlowski, 2013).

At present, most of the research on carbon footprint in China is mainly macroscopic. This paper focuses on the carbon footprint research of sludge treatment and disposal, and provides the basis for the carbon emission reduction work of the sludge industry.

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2 METHODOLOGY

2.1 Project Introduction

At present, “ZhuYuan sludge incineration project” is the largest sewage sludge drying and incineration project that has been operated in China. The scale of this project is 150 t/DS, and the Sludge calorific value is 13700 kJ/kg. The project mainly includes sludge receiving and storage system, sludge drying system, sludge incineration system, waste heat utilization system, flue gas treatment system and auxiliary system. The sludge is dried by indirect drying method, and the heat source is steam. The sludge is incinerated by fluidized bed incinerator.

2.2 Boundary of Research System

In the study of sludge life cycle assessment, it is generally regarded as the starting point of life cycle evaluation, and the scope of the study includes the whole process from production, transportation, recycling, and treatment to final disposal. This paper focuses on the research on the disposal and disposal parts. Along with the sludge itself entering the system, it also includes auxiliary energy and other raw materials; the output of the system is useful products and recycled energy.

Sludge treatment processes and the disposal route are presented in Figure 1. “Thickening” and “Dewatering” process are finished in Waste water treatment plant. “Drying” and “Incineration” process are finished in Sludge treatment plants. Research boundary is limited to sludge treatment plant.

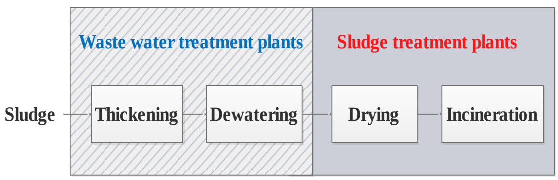

Figure 1: Sludge treatment processes and disposal routes.

2.3 Carbon Footprint Method

The Carbon footprint is defined as the total amount of greenhouse gases (GHG) produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO_2). It is a common method to calculate the impacts of human activities on Global Warming (IPCC, 2006).

Although the study found many gases affecting the climate system, only 6 major types of greenhouse gases were included in the “Kyoto Protocol”, including CO_2, CH_4, N_2O, HFCs, PCFs and SF in the carbon footprint assessment. As the quantification of these gases cannot be directly measured, they are estimated by calculating GHG emissions of each processes involved in the studied activities. The amount of each gas is then converted with an emission factor in CO_2 equivalent (CO_{2eq}) according to their Global Warming Potential (GWP), which showed in Table 1 (IPCC, 2006).

Table 1: Considered gases in carbon footprint and their Global Warming Potential at 100 years (GWP_{100}).

Formula	GWP_{100}
CO_2	1
CH_4	21
N_2O	310
HFCs	124-14800
PCFs	7390-10300
SF	17200

GHG emission of sludge treatment can be divided into direct part and indirect part:

- Direct part: GHG emissions directly occurring in sludge treatment and disposal.
- Indirect part: GHG emissions caused by electricity and fuel consumption during sludge drying and incineration process.

2.4 Calculation Method

At present, the domestic calculation methods of GHG emissions in sludge treatment and disposal process are mainly divided into actual measurement method and model estimation method.

The actual measurement method needs to measure the relevant parameters of the emission source or the operating equipment through the actual testing method, and calculate the carbon emissions by the measured data approved by the environmental protection department. Most of calculations used model estimation method. These studies are of great guiding significance, but the results are largely dependent on the hypothesis and scenario analysis.

In order to make the research more practical, the carbon footprint of “ZhuYuan sludge incineration project” is calculated by actual measurement method and model estimation method.

3 MODEL ESTIMATION METHOD

3.1 Calculation Method of Drying

The carbon emission during the sludge drying process is mainly energy consumption, and the calculation method is as shown in Equation 1.

$$CO_2=M1\cdot(EC1\cdot F_{electric} + EC2\cdot F_{natural\ gas}) \quad (1)$$

M1: The mass of water reduction during drying
EC1: Specific energy consumption (electric)
$F_{electric}$: CO_2 emission factor (electric)
EC2: Specific energy consumption (natural gas)
$F_{natural\ gas}$: CO_2 emission factor (natural gas)

3.2 Calculation Method of Incineration

Carbon emissions from sludge incineration include Energy source CO_2, Biogenic source CO_2 and Alternative CO_2, and the calculation method is as shown in Equation (2) ~ (6).

$$CO_2=M2\cdot(EC3\cdot F_{electric} + EC4\cdot F_{electric}) \quad (2)$$

M2: Dry sludge quality
EC3: Specific energy of Wet flue gas purification system (electric)
EC4: Specific energy of SNCR (electric)

$$CO_2=M2\cdot CC\cdot\eta 1\cdot 44/12\cdot \quad (3)$$

CC: Carbon content in sludge
η: Combustion carbon oxidation factor

$$CO_{2CH4}=M2\cdot F_{CH4}\cdot \quad (4)$$

F_{CH4}: Emission factor of CH_4

$$CO_{2N2O}=M2\cdot F_{N2O}\cdot \quad (5)$$

F_{N2O}: Emission factor of N_2O

$$CO_2=M2\cdot Hv\cdot\eta 2\cdot F_{diesel}/Hvd \quad (6)$$

HV: Sludge calorific value
η2: Energy utilization rate
F_{diesel}: CO_2 emission factor (diesel)
Hvd: Diesel calorific value

3.3 Estimation Result

In the model estimation method, the calculation parameters of sludge drying and incineration process are shown in Table 2. In the drying stage, due to the different use of equipment and the actual operation, it causes difference in energy consumption, and there is still such a situation in the incineration stage, that is, different flue gas treatment equipment and different working conditions will lead to the different energy consumption of the wet scrubbing tower and the SNCR system (Liu et al., 2013).

The discharge equivalent of CO_2 in the sludge incineration process is 1546.6~1709.9 kg CO_2/t DS, and the emission equivalent of the energy source CO_2 is 737.7~988.0 kg CO_2/t DS, and the emission equivalent of the biological source CO_2 is 1432.5 kg. Alternative CO_2 comes from the energy produced by the sludge incineration. This part of the energy can be used to compensate for the consumption of the system (Showed as Table 3).

Table 2: Calculation parameters of GHG emission.

Unit	Category	Parameter	Value (Ministry of environmental protection)
Drying	Energy source CO_2	M	2.5 kg
		EC1	100-200 kWh/m^3
		EC2	2750 kJ/kg
Incineration	Energy source CO_2	CC	36%
		η1	95%
		EC3	6~19 kWh/t DM
		EC4	40~50 kWh/t DM
	Biogenic source CO_2	F_{CH4}	24.25 g CH_4/t DM
		F_{N2O}	990 g N_2O/t DM
	Alternative CO_2	Hv	13700 kJ/kg
		Hvd	43.0 TJ/Gg
		η2	70%

Table 3: GHG emission.

Unit	Emission type	Emission value (kg)	GWP	CO_2eq (kg CO_2/t DS)
Drying	Energy source CO_2t	684.9~916.9	1	684.9~916.9
Incineration	Energy source CO_2	49.8~71.1	1	49.8~71.1
	Biogenic source CO_2	1125.1	1	1125.1
	Emission of CH_4	0.024	21	0.504
	Emission of N_2O	0.99	310	306.9
	Alternative CO_2	-710.6	1	-710.6

4 ACTUAL MEASUREMENT METHOD

4.1 Energy Source CO_2

The energy source CO_2 emission from "ZhuYuan sludge incineration project" mainly includes the consumption of power, light diesel, activated carbon, NaOH and $Ca(OH)_2$. The specific value was showed in Table 4. The discharge equivalent of energy source CO_2 is 1891.96 kg CO_2/t DS.

It is necessary to explain that the energy generated by the sludge incineration is not sufficient to support the drying of the sludge, so the external energy is needed to fill the dry energy gap, and the steam from the "Waigaoqiao power plant" is used in this project.

Table 4: Energy source CO_2 emission.

Entry	Consumption	CO_2eq (kg CO_2/t DS)
Power	578.97 kWh/t DS	537.28
External steam (used for drying)	996.14 kWh/t DS	924.42
light diesel	124 kg/t DS	394.20
activated carbon	1 kg/t DS	6
NaOH	17.86 kg/t DS	20.90
$Ca(OH)_2$	9.41 kg/t DS	9.17

4.2 Biogenic Source CO_2

The average carbon content in dehydrated sludge was 32%, and the average carbon content in fly ash was 1.1% after burning. According to the estimated method proposed by the IPCC (2006), the CO_2 emission of biological source was 1154.6 kg CO_2 /t DS.

4.3 Alternative CO_2

Energy produced by the sludge incineration is all self-used, one part is used for primary air heating in incinerator and the other is used in the waste heat boiler to produce steam to drying sludge, so it is no longer included in the emission statistics.

5 METHOD COMPARISON

Using the model estimation method, the discharge equivalent of CO_2 in the sludge incineration process is 1546.6~1709.9 kg CO_2/t DS; Using the actual measurement method, the discharge equivalent of CO_2 in the sludge incineration process is 3046.6 kg CO_2/t DS. It can be seen that there are large differences in the calculation of CO_2 emission equivalents by different methods. The main reasons are as follows: 1. The power consumption in the actual measurement method is the total power consumption of the entire engineering operation facility, which is greater than the power consumption of the specified equipment in the model estimation method; 2. The specific energy consumption in the model estimation is greatly affected by the assumptions, equipment and working conditions, and there is a big difference with the actual operating conditions. 3. The energy available for sludge incineration after model incineration depends on the assumed utilization value. For the estimation, this is also quite different from the actual use value of the energy in the measured method.

6 OPTIMIZATION SUGGESTION

Through analysis, it can be seen that the energy source CO_2 emissions in the dry process and the flue gas treatment process account for a large proportion. Drying process is one of the most important links of CO_2 emissions. The energy consumption of the sludge drying technology is related to the dry form. Therefore, the selection of a dry process with lower energy consumption can effectively reduce CO_2 emissions.

The energy consumption of drying is still related to the type of heat source chosen. From the perspective of reducing carbon emissions, when the flue gas temperature is high enough and transport distance is relatively short, it is preferable to use waste heat flue gas of large-scale industrial and environmental protection infrastructure, such as waste incinerator, power station, chemical facilities, etc.

In addition, the energy utilization rate of the incineration system should be increased, which can increase the value of Alternative CO_2.

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