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Greenhouse gases emissions accounting for typical sewage sludge digestion with energy utilization and residue land application in China

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ABSTRACT

About 20 million tonnes of sludge (with 80% moisture content) is discharged by the sewage treatment plants per year in China, which, if not treated properly, can be a significant source of greenhouse gases (GHGs) emissions. Anaerobic digestion is a conventional sewage sludge treatment method and will continue to be one of the main technologies in the following years. This research has taken into consideration GHGs emissions from typical processes of sludge thickening + anaerobic digestion + dewatering + residue land application in China. Fossil CO_2, biogenic CO_2, CH_4, and avoided CO_2 as the main objects is discussed respectively. The results show that the total CO_2-eq is about 1133 kg/t DM (including the biogenic CO_2), while the net CO_2-eq is about 372 kg/t DM (excluding the biogenic CO_2). An anaerobic digestion unit as the main GHGs emission source occupies more than 91% CO_2-eq of the whole process. The use of biogas is important for achieving carbon dioxide emission reductions, which could reach about 24% of the total CO_2-eq reduction.

1. Introduction

The development of wastewater treatment in China has increased the amount of sewage sludge during the past decades. Sewage treatment plants discharged about 20 million tonnes of wet sludge (moisture content (MC) is 80%) in 2009 (Wang, 2010).

Anaerobic digestion (Wang et al., 2009) is a widely used biological method to treat sewage sludge, especially after the application of pretreatment technologies that enhance the digestibility of sludge and biogas productivity, such as thermal hydrolysis (Wang et al., 2009), chemical pretreatment including ozone, acids and alkali (Lin et al., 1997; Kopp et al., 1997), mechanical disintegration (including pressure homogenization); centrifugation (Dohányos et al., 1997), sonication(Nah et al., 2000; Salsabil et al., 2009; Apul and Sanin, 2010; Lafitte-Trouqué and Forster, 2002; Na et al., 2007), microwave(Idris et al., 2004; Menéndez et al., 2004), and freezing and thawing (Müller, 2001; Werle and Wilk, 2010).

Greenhouse gases (GHGs) have attracted public attention because of their implications on climate change. Here, the GHGs include biogenic GHGs (including biogenic CO_2 and CH_4) that were emitted from sludge degradation, fossil CO_2 that was directly proportional to energy consumption (EC) in the treatment process, and avoided CO_2 via the reutilization of energy and residue. Studies increasingly started to focus on the contribution to the global warming (GW) of sludge treatment. IPCC (2006) proposed the calculation method for CH_4 of sludge digestion unit and encourages the use of the specific-country data and default values when the specific data are not available. Soda et al. (2010) developed an energy consumption model for evaluating the energy consumption and GHGs emission of sewage sludge treatment processes, which is based on the data from sewage sludge treatment plants in Osaka, Japan. There is one report on the calculation of GHGs emission from a 600 t/d sludge treatment plant in Dalian (Chen et al., 2010). Some researchers (Strauss and Wiedemann, 2000; Keller and Hartley, 2003; Hospido et al., 2005; Tilche and Galatola, 2008) use the life cycle assessment to analysis the global warming potential (GWP) of an existing sludge treatment plant and compare the GWP between different sludge treatment technologies. Most of the existing studies are based on specific-plants and do not provide a general calculation method for GHG emissions resulting from a sludge treatment system. Especially in China, the calculation of GHG emissions for sludge treatment system is only in its early stages. Currently, no data could reflect the contribution of the sludge thickening + anaerobic digestion + dewatering + residue land application system to national GHG emissions. The purpose of this study is to calculate the GWP in the form of CO_2-eq of the above mentioned sludge treatment system and give an overview

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on how much it contributes to the national GHG emissions. Therefore, it will be valuable for policy planning and technology selection.

2. Methodology

2.1. Scope

2.1.1. Function unit

The function unit is used to describe the system input. Here, all the calculations are based on mixed sludge with 1 tonne DM.

2.1.2. Process description and system boundaries

The mixed sludge is thickened, anaerobically digested, and dewatered before finally being applied to the land. The volatile solid (VS) of the mixed sludge is about 60% of DM. The MC of the mixed sludge is about 99% and the MC after thickening and dewatering is about 96% and 80%, respectively. The block diagram of this scenario is shown in Fig. 1. This process has the advantage of being able to recycle digestion gases and fertilizing elements.

The system boundaries are as follows:

(a) As proposed by the IPCC report (IPCC, 2007) and other research studies (Soda et al., 2010), the construction of different operation facilities, including machinery and electric installations, was not considered and only the operation stage was taken into account for the analysis.

(b) In this paper, system GHG emission refers to the sum of fossil CO_2, biogenic CO_2, and methane calculated in the form of $CO_{2\text{-eq}}$. Total GHG emissions of the system equals to the sum of system GHG and avoided CO_2 (negative value). Net GHG emissions can be calculated by subtracting the biogenic CO_2 from the total GHGs.

(c) Fossil CO_2 refers to CO_2 emitted by energy consumption during the operation.

(d) In sludge thickening and dewatering units, the sludge retention time is relatively short. It is assumed that no biodegradation occurred. Thus, the biogenic CO_2 is not discussed. Only the fossil CO_2 is considered.

(e) It is assumed that sludge digestion is operated under mesophilic conditions and recovered CH_4 can be used to produce heat and electricity. CH_4 emission refers to dispersive CH_4 which is relevant to recovery rate. Biogenic CO_2 refers to those gases emitted by sludge degradation and recovered CH_4 combustion. Avoided CO_2 refers to CO_2 substituted by CH_4 recovery for heat and electricity generation.

(f) As regards the residue land application unit, the sludge residue is hypothesized to be produced all year round, but it can only be spread on arable land after appropriate treatment in spring and autumn; this implies that the products are stocked up for several months before their use. The energy consumption for storage, transportation, and machinery fuel are encompassed in the inventory. The biogenic GHG emission is linked to organic matter anaerobic digestion during storage and after spreading. The most important GHGs in the land application unit are CH_4 and CO_2. N_2O was not considered due to its low concentration (Kaparaju and Rintala, 2011). Sludge residue land application can replace the use of chemical fertilizers and reduce carbon emissions during the production of chemical fertilizers, as well. Here, avoided CO_2 refers to the CO_2 substitution of fertilizer manufacture. The calculation is based on the amount of Nitrogen (N) produced in the form of ammonium nitrate and Phosphorus (P) in the form of superphosphate.

2.2. Calculation methods and coefficient selection

2.2.1. Fossil CO_2 output calculation method

The fossil CO_2 emission is based on the energy consumption required during the treatment process and on the effective CO_2 emission factor of electricity or diesel as shown in the following equation.

$$CO_2\text{Fossil}_i = \text{DM}_i \cdot (\text{EC} \cdot f_{\text{tr}} + \text{EC}' \cdot f'_{\text{tr}}) \tag{1}$$

where CO_2 Fossil$_i$ is the fossil CO_2 emissions resulting from sludge treatment process *i (kg);* DM$_i$ the mass of dry matter in the sludge in process *i* (t); EC the electricity consumption of the sludge treatment process per ton of DM in the sludge (kWh/t DM); EC′ the diesel consumption of the sludge treatment process per ton of DM in the sludge (kg diesel/t DM); f_{tr} the effective CO_2 emission factor of electricity (kg CO_2/kWh); f'_{tr} is the effective CO_2 emission factor of diesel (kg CO_2/kg diesel); *i* the thickening, digestion and land application process.

Gravity thickening and centrifugal dewatering are selected when calculating the GHG emissions from the designed scenario.

The VS degradation rate of anaerobic digestion is normally 40–50% (Wang and Qin, 2007). Here, the average number 45% is used. Thus, the residue is about 0.73 t DM after digestion. That also means the DM of residue land application is about 0.73 t.

The effective CO_2 emission factor (f_{tr}) of electricity is about 0.785 kg CO_2/kWh (Cao et al., 2010). The effective CO_2 emission factor (f'_{tr}) of diesel is around 74100 kg CO_2/TJ (IPCC, 2006). That is equal to about 3.186 kg CO_2/kg diesel.

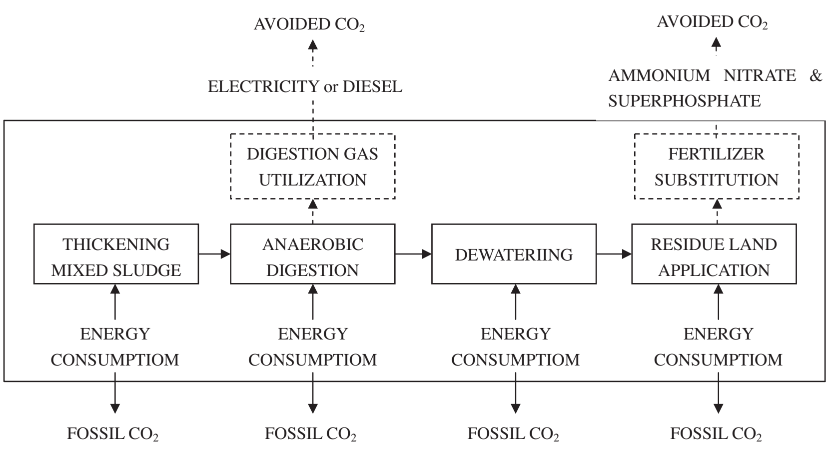

Fig. 1. A block diagram of the scenario of sludge management.