GREENHOUSE GAS EMISSIONS FROM ANAEROBIC DIGESTION PLANTS

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ABSTRACT

This study investigated emissions of CH4, N2O and NH3 from nine anaerobic digestion plants that treat biowaste. The treatment is in form of mechanical pre-treatment, anaerobic digestion followed by a composting with or without intensive aeration. The exhaust gases from the mechanical and anaerobic steps are treated by biofilters. The emission sources at the plants consisted of biofilters, combined heat and power units (CHP), liquid digestate treatment systems (LTS) and open composting windrows of the solid digestate. Overall, the emission factors were 0.4 - 16 kg (Mg biowaste)-1 for CH4, 7 - 170 g (Mg biowaste)-1 for N2O and 41 - 6,032 g (Mg biowaste)-1 for NH3. Open composting windrows of solid digestate resulted in high emissions of CH4 and N2O. Intensive aeration of the solid digestate could reduce greenhouse gas emissions.

Keywords: greenhouse gas, emissions, anaerobic digestion, windrows, organic waste, methane.

1. INTRODUCTION

Anaerobic digestion for treatment of biowaste is rapidly gaining interest in developed and developing countries [1, 2]. The treatment is essentially based on the activities of microorganisms that transform organic substances into biogas [3]. Biogas is used as renewable energy source, and nutrients in the residue can be recovered in agriculture as fertilizer or soil conditioner [4]. In addition, AD of biowaste is attracting attention as an effective method to reduce Greenhouse gas (GHG) emissions according to Kyoto protocol [4]. According to the life cycle analysis (LCA), AD results in negative GHG emissions. The total greenhouse gas (GHG) emissions for AD can reduce up to one tonne CO2 equivalent/ Mg separated organic waste [5]. Actually, many studies have been conducted to show the benefits of AD treatment, for instance the works of [2, 4, 6 and 7]. However, there is still missing an overall evaluation of GHG emissions during treatment. For example, the GHG emissions associated to the pre-treatment and post-treatment of AD were often excluded in previous studies. In fact, AD plants may have fugitive emissions of CH4, N2O and NH3. The aim of the study was to investigate emission
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factors of CH₄, N₂O and NH₃ g (Mg biowaste)^{−1} and to compare emission sources in the plants. Additionally, the efficiency of biofilters was taken into account. Nine operating AD plants, two wet digestion plants, four dry digestion plants and three solid digestion plants, were evaluated.

2. MATERIALS AND METHODS

2.1. Measured locations and emission determinations

The emission sources at the plants consisted of biofilters, combined heat and power units (CHP), liquid digestate treatment systems (LTS) and open composting windrows of the solid digestate. The detailed inventories of the AD plants are listed in Table 1.

Table 1. Processing parameters of the anaerobic digestion plants.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Wet digestion</th>
<th>Dry digestion</th>
<th>Solid digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>AD 1</td>
<td>AD 2</td>
<td>AD 3</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Temp.</td>
<td>meso</td>
<td>thermo</td>
<td>thermo</td>
</tr>
<tr>
<td>HRT (day)</td>
<td>-</td>
<td>20</td>
<td>15-30</td>
</tr>
<tr>
<td>Digetate Separation</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Composting</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

2.1.1. Biofilter

The gas inlet and outlet of biofilter was analysed at each plant for 1 week. At capped biofilters the treated air left the biofilter in a chimney. Here the gases were measured (biofilters at plants 1, 4, 6 and 9). At open biofilter (at plants 2, 3, 5, 7 and 8), 16 m² of the biofilter (4x4 m) was covered by a thin foil. Concentrations of the treated gases were measured under the foil. Continuously monitored parameters included TOC, CH₄ and N₂O. TOC was measured by flame ionisation detector (Bernath Atomic 3006) while CH₄ and N₂O were measured by an infrared gas analyser. Gas concentrations in the treated and untreated exhaust air were recorded every minute.

To control the accuracy of the infrared gas analyser, exhaust gases were sampled manually by evacuated headspace vials and subsequently analysed on CH₄ and N₂O by GC (ECD/FID) in the laboratory. A manual discontinuous analysis was applied for NH₃ measurement: NH₃ was extracted from the waste gas stream by absorbing it in sulfuric acid and subsequently measured.
colorimetrically in the laboratory. NH₃ samples of treated and untreated gases were collected twice. Air fluxes to the biofilter were measured by an anemometer (testo 435) or micromanometer (Müller Instruments EPM-300-BA, Germany). It was assumed that the volumes of treated and untreated air were the same.

2.1.2. Open composting windrows

To measure GHG emissions from composting windrows, a tunnel covers an area of around 50 m² with a length of 10 m and a width of 5 m. The height of the tunnel may vary from 1.5 to 2 m. Two ventilators are used to ventilate the tunnel from one side. The ventilation rate is fixed at 1000 m³ h⁻¹. Fresh air enters the tunnel from the front. In the tunnel, gas is emitted into the fresh air and leaves the tunnel at the rear. At the outlet, a Teflon tube (4 mm in diameter) is installed 0.5 m above the windrows and used for gas sampling. The gas is pumped via a cooler to an infrared gas N₂O and CH₄ analyser (Uras, ABB). The infrared detector has a sensitivity of 0.1 mg/m³ for N₂O and 1 mg/m³ for CH₄. When the tunnel was installed, it took ten to twenty minutes for GHG concentrations to be constant. GHG concentrations were then recorded every minute for one hour. Air fluxes were determined using an anemometer (testo 435) or a micromanometer (Müller Instruments EPM-300-BA, Germany). In parallel, 60L of outgoing air were flushed through two flasks containing 40 mL of a 0.05 M H₂SO₄ solution. NH₃ was trapped in the solution as NH₄⁺ and subsequently analysed colorimetrically in the laboratory.

2.2. Other measuring points (e.g. CHP, receiving and pre-treatment hall, liquid digestate treatment systems (LTS))

Other emission sources were point sources with preinstalled sampling points. For one hour the TOC concentrations were recorded every minute by FID. In parallel, gas samples were taken regularly using evacuated headspace vials for CH₄ and N₂O. For NH₃, samples were taken by absorbing it in sulfuric acid solution. Air fluxes were also determined by measuring velocity (m/s) and cross section area (m²).

LTS: After anaerobic digestion, the digestate is dewatered by a second centrifuge. The solid digestate is mixed with green waste and used for composting. The liquid is treated in nitrification and denitrification tanks.

CHP: CHPs consist of a combustion engine and a generator. Biogas is used to generate electricity and heat in these combustion engines.

2.3. Calculations of emissions factors for anaerobic digestion plants

The emission factors of CH₄, N₂O and NH₃ g (Mg biowaste)⁻¹ were calculated using the aeration rates and concentrations of gases. The emission rates and emission factors for each gas were calculated using the following formula:

\[
E_{MF} = \frac{E \times Q}{1000} \quad \text{(g h⁻¹) [8];} \\
E_f = \frac{(E_{MF} \times 24 \times 7)}{M_w} \quad \text{g (Mg waste)⁻¹ [8]}
\]

with: E: concentration (mg x m⁻³), Q: air flow (m³ x h⁻¹), E_{MF}: emission mass flow (g x h⁻¹), 
M_w: total mass of incoming waste (Mg per week), E_f: emission factor g (Mg waste)⁻¹

The emissions were calculated in form of CO₂ equivalent according to Intergovernmental Panel on Climate Change (IPCC) in 2007. N₂O and CH₄ are potential GHG with respective
global warming potentials 298 and 25 times higher than that of CO₂ respectively. Additionally, it was assumed that the CO₂ equivalent of NH₃ is 2.98 [8].

\[ E_{\text{fCO₂ equivalent}} = \sum (E_{\text{fCH₄}} \times 25 + E_{\text{fN₂O}} \times 298 + E_{\text{fNH₃}} \times 2.98) \]  

Overall GHG emissions from AD plants were calculated by the sum of emissions of CH₄, N₂O and NH₃ from open emission sources such as biofilter, CHP, open composting windrows and liquid digestate treatment systems. Emissions from machinery and energy used in the plants were not considered in the calculations.

\[
\begin{align*}
E_{\text{plant1}} &= \sum (E_{\text{BF}} + E_{\text{OW}} + E_{\text{LTS}}) \\
E_{\text{plant2}} &= \sum (E_{\text{BF}} + E_{\text{OW}}) \\
E_{\text{plant3}} &= \sum (E_{\text{BF}} + E_{\text{CHP}}) \\
E_{\text{plant4}} &= \sum (E_{\text{BF}} + E_{\text{CHP}}) \\
E_{\text{plant5}} &= \sum E_{\text{BF}} \\
E_{\text{plant6}} &= \sum (E_{\text{BF}}) \\
E_{\text{plant7}} &= \sum (E_{\text{BF}} + E_{\text{CHP}}) \\
E_{\text{plant8}} &= \sum (E_{\text{BF}} + E_{\text{OW}}) \\
\end{align*}
\]

\[ E_{\text{plant}} = \sum (E_{\text{BF}} + E_{\text{CHP}}) \]

3. RESULTS AND DISCUSSION

3.1. Emission factors of CH₄, N₂O and NH₃ from open emission sources in AD plants

The emission factors of CH₄ varied from 16 to 819 g (Mg biowaste)⁻¹ for liquid treatment system (LTS), from 50 to 1500 g (Mg biowaste)⁻¹ for CHP, and from 0.4 to 15.4 kg (Mg biowaste)⁻¹ for open windrows (Figure 1). Liquid digestate still contains potential to form CH₄ [6]. Thus, CH₄ emissions still occur in treatment systems of liquid digestate. Biogas produced at the AD plants is burned in CHPs to produce electricity and heat. Since the combustion process is not 100 %, some CH₄ escapes unburned into the atmosphere. By this way, CHP contributes to CH₄ emissions.

The emission factors of N₂O were in the range of 1.22 to 37.57 g (Mg biowaste)⁻¹ for LTS, 0.1 to 2.7 g (Mg biowaste)⁻¹ for CHP, and 36 to 201 g (Mg biowaste)⁻¹ for open windrows. The emissions of N₂O at the CHP were insignificant, while the N₂O emissions from LTS and open windrows need to be considered. The results are in line with the findings of [4, 8].

The emission factors of NH₃ were in the range of 0.1 to 0.16 g (Mg biowaste)⁻¹ for LTS, 0.03 to 1.16 g (Mg biowaste)⁻¹ for CHP and 65 to 3327 g (Mg biowaste)⁻¹ for open windrows. The emissions of NH₃ from the LTS and CHP were low, while open windrows had high emissions of NH₃.
3.2. Emissions factors of CH₄, N₂O and NH₃ at the AD plants

The CH₄ emission factors from AD plants were from 444 to 1,5713 g (Mg biowaste)⁻¹ (Figure 2). The median CH₄ emission factor was 3,397 g (Mg biowaste)⁻¹. The plants 1, 2 and 9 with open composting windrows showed highest CH₄ emissions. The CH₄ emission factors from composting windrows were 15,452, 5,763 and 10,254 g (Mg biowaste)⁻¹ which contributed relatively to 95 %, 73 % and 96 % and of the total CH₄ emissions at the plants 1, 2 and 9 respectively.

Emission factors of CH₄ from CHPs were measured only in the plants 3, 4 and 7. CH₄ emission factors from CHPs varied from 52 to 2,040 g (Mg biowaste)⁻¹. The results were higher than a previous study: [4] reported that the emission factors of CH₄ from CHP ranged from 16 to 819 g (Mg biowaste)⁻¹.

The emission factors of CH₄ from biofilters varied from 236 to 5,237 g (Mg biowaste)⁻¹. The results are in line with the findings of [4, 8] but comparatively higher than the results of [9], who found that the emission factors of CH₄ were about 100 g (Mg waste)⁻¹.
The emission factors of N\textsubscript{2}O were in a range of 7-170 g (Mg biowaste)\textsuperscript{-1} (Figure 3). Median N\textsubscript{2}O emission factor was 67 g (Mg biowaste)\textsuperscript{-1}. N\textsubscript{2}O emissions from open composting windrows contributed significantly to the total N\textsubscript{2}O emissions of the AD plants. The contributions of open composting windrows to the total N\textsubscript{2}O emissions were 76 %, 80 % and 94 % at the plants 1, 2 and 9 respectively. The N\textsubscript{2}O emissions from CHPs were from 0.5 to 5 g N\textsubscript{2}O (Mg biowaste)\textsuperscript{-1} and contributed only 2-7 % to the total N\textsubscript{2}O emissions. The N\textsubscript{2}O emission factors from biofilters ranged from 6.7 to 78 g (Mg biowaste)\textsuperscript{-1}. The N\textsubscript{2}O emissions from LTS contributed in the range of 2-27 % of the total N\textsubscript{2}O emissions.

The emission factors of NH\textsubscript{3} were in the range of 41-6,032 g (Mg biowaste)\textsuperscript{-1} (Figure 4). Median NH\textsubscript{3} emission factor was 101 g NH\textsubscript{3} (Mg biowaste)\textsuperscript{-1}. Open composting windrows contributed 91 %, 86 % and 99 % to the total NH\textsubscript{3} emissions at the plants 1, 2 and 9 respectively. High NH\textsubscript{3} emissions at the plant 3 were due to conversion of NH\textsubscript{4}\textsuperscript{+} in digestate to NH\textsubscript{3} at a high pH and a high temperature in the belt dryer.

3.3. The contribution of CH\textsubscript{4}, N\textsubscript{2}O and NH\textsubscript{3} from AD plants to global warming potential

The emission factors were transferred into CO\textsubscript{2} equivalents according to IPCC (2007). The overall CO\textsubscript{2} emissions were in a range from 31 to 435 kg (Mg biowaste)\textsuperscript{-1}. The CH\textsubscript{4} emissions from AD plants were more important than the emissions from N\textsubscript{2}O and NH\textsubscript{3} (Figure 5A). The emissions of CH\textsubscript{4} accounted from 36 - 92 % while the emission of N\textsubscript{2}O and NH\textsubscript{3} contributed from 6.9 - 30 % and from 0.08 – 58 % respectively to the overall CO\textsubscript{2} emissions. The median CO\textsubscript{2} equivalent emission was 105 kg CO\textsubscript{2} (Mg biowaste)\textsuperscript{-1}. The results were in line with a previous study. [4] reported that an AD plant contributed up to 111 kg CO\textsubscript{2} equivalent (Mg waste)\textsuperscript{-1}. The AD plants with open composting windrows (1, 2 and 9) showed higher CO\textsubscript{2} equivalent emissions than the AD plant without open composting windrows.

Figure 5B shows the net total of CO\textsubscript{2} equivalent from different emission sources at AD plants. The open composting system resulted in high GHG emissions accounting from 73 to 96 % to the total emissions at plants 1, 2 and 9. CHP contributed from 5 to 50 % to the total emissions at plants 3, 4 and 7. The liquid treatment system resulted in insignificant (3.7 %) to the total CO\textsubscript{2} equivalent emissions at plant 1.
**4. CONCLUSIONS**

Anaerobic digestion plants are a source of GHG emissions. Emission sources are biofilter, open windrows, CHP and liquid digestate treatment system. Especially, open windrows have adverse impacts on environment. Inside the AD plants, the emissions at the receiving and pre-treatment processes play less important roles, whereas the separation of digestate into a solid and a liquid phase results in high GHG emissions.

Based on the results, the emissions factors were 3397 g (Mg waste)\(^{-1}\) for CH\(_4\) (85 kg CO\(_2\) equivalent) and 67 g (Mg waste)\(^{-1}\) for N\(_2\)O (20 kg CO\(_2\) equivalent). In Germany, ca. 10.5 million tonnes biowaste are produced per year. If all biowaste would be treated by AD, they would result in contribution of 0.31 % for N\(_2\)O and 1.83 % for CH\(_4\) to the overall national GHG emissions (base: 2012).

**REFERENCES**


