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Comparative use of different emission measurement approaches to determine methane emissions from a biogas plant

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ABSTRACT

A sustainable anaerobic biowaste treatment has to mitigate methane emissions from the entire biogas production chain, but the exact quantification of these emissions remains a challenge. This study presents a comparative measurement campaign carried out with on-site and ground-based remote sensing measurement approaches conducted by six measuring teams at a Swedish biowaste treatment plant. The measured emissions showed high variations, amongst others caused by different periods of measurement performance in connection with varying operational states of the plant. The overall methane emissions measured by ground-based remote sensing varied from 5 to 25 kg h^{-1} (corresponding to a methane loss of 0.6–3.0% of upgraded methane produced), depending on operating conditions and the measurement method applied. Overall methane emissions measured by the on-site measuring approaches varied between 5 and 17 kg h^{-1} (corresponding to a methane loss of 0.6 and 2.1%) from team to team, depending on the number of measured emission points, operational state during the measurements and the measurement method applied. Taking the operational conditions into account, the deviation between different approaches and teams could be explained, in that the two largest methane-emitting sources, contributing about 90% of the entire site's emissions, were found to be the open digestate storage tank and a pressure release valve on the compressor station.

1. Introduction

In Europe, the production of biogas and biomethane for the energy or fuel sectors has increased in the past years. Several European countries, including Germany, Sweden and Denmark, have national programmes for the future development and implementation of biogas in their energy systems (DEA, 2012; EEG, 2014). Biogas is regarded as a climate-neutral fuel, since carbon in the biogas was recently taken up by plants from atmospheric carbon dioxide. The carbon dioxide released when combusting biogas is therefore regarded as being biogenic and not contributing to climate change. Furthermore, any substitution of fossil fuels by biogas will lower total carbon dioxide emissions. Finally, using substrates like manure for biogas generation can reduce methane emissions elsewhere in the biogas chain, for example emissions from manure and digestate storage (Amon et al., 2006). Biogas consists of 50–70% methane, which is a very potent greenhouse gas with a global warming potential 28–34 times higher than carbon dioxide (Myhre et al., 2013). Thus, any biogas emitted from a biogas plant into the atmosphere will contribute to climate change and increase the carbon footprint of the plant.

For environmental assessments of biogas technology and the production chain, knowledge about methane emissions from the production site is required. The only continuous emission source in biogas plants is the off-gas from the gas utilisation unit, while most methane emissions are diffusive by nature and are often the result of several leakages, open digestate storages, ventilated buildings, etc. Their diffusive and dynamic nature, together with large plants, challenge the quantification of these emissions, and even though several measuring methods are available, very few are standardised. In general, two main approaches can be used for gas emission quantification: on-site and ground-based remote sensing approaches.

The on-site approach is the approach most commonly used (Daniel-Gromke et al., 2015; Liebetrau et al., 2013; Reinelt et al.,

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2016; Westerkamp et al., 2014). In addition to known emission sources, the on-site approach identifies unknown sources by means of leakage surveys. After identification, the methane emission from each individual source is quantified using different measuring methods and analytical instrumentation. Knowledge about methane emissions from individual sources is of importance to the plant operator when implementing abatement measures at the plant. However, in order to quantify the emission the source is often encapsulated (dynamic or static chamber), which always affect the emission due to temperature, concentration and pressure changes. Furthermore, the emission from the source is only measured over a relatively short time interval and the emission has to be assumed as constant. In reality the emission rate of diffusive sources can change in the course of a day.

The ground-based remote sensing approach includes different methodologies and measures emissions a good distance away from the plant, thus providing plant-integrated emission numbers (Flesch et al., 2011; Groth et al., 2015; Hrad et al., 2014; Westerkamp et al., 2014; Yoshida et al., 2014; Jensen et al., 2017). The use of remote sensing enables the simultaneous capture of the whole plant emissions and with it includes emission sources that might be missed by the on-site approach without affecting the plant operation. So the remote sensing approach is able to monitor time-independent and/or operational emissions over longer periods of time compared to the on-site approach. However, remote sensing approaches rely on atmospheric transport processes and are affected by changes in the atmospheric conditions. Furthermore, the topography of the surrounding area and the existence of additional emission sources (e.g. farms, landfills, etc.) next to plant have to be considered.

The objective of this study was to conduct a comparison study where methane emissions from a full-scale biogas plant were quantified using different measuring methods. Measurements were performed by six professional measuring teams and included four teams applying leakage location and on-site emission measuring methods, and two teams applying ground-based remote sensing methods. The five-day measuring campaign (September 8th to 12th, 2014) was carried out at a biowaste treatment plant located in Sweden. To the best of the authors' knowledge, this is the first emission measurement comparison study performed at a biowaste treatment plant.

2. Material and methods

2.1. Biowaste treatment plant

The investigated biowaste treatment plant is located in Linköping, Sweden, and has been in operation since 1997. In 2014, the plant treated about 103,500 Mg of organic waste, consisting of about 20% slaughterhouse waste, 28% food industry waste and 48% household food waste. The waste is pretreated on site. The pretreatment hall is encapsulated and evacuated by a blower, and the exhaust leads to an area biofilter to reduce odour emissions. Afterwards, the waste is mixed in a homogenisation tank and then hygienised in a hygienisation tank for 1 h at a temperature of 70 °C. The anaerobic digestion (AD) process is based on wet fermentation with three parallel primary digesters (each 3700 m^3) and one post digester (6000 m^3). Digestate from the AD process is sieved to remove visible impurities such as plastics, and then the liquid fraction is stored in an open tank (4500 m^3 storage volume; 2000 m^3 filling level in September 2014). At the end of the measurement campaign, a digestate sample from the post digester was taken and analysed in the laboratory. The residual methane potential of the digestate amounted to 165 m^3_{STP} Mg VS^{-1} (after 58 days) measured at a temperature of 37 °C. The plant produced 98,500 tons of wet bio fertiliser in 2014, which was sold to farmers. In 2014, the plant produced 17,000,000 m^3_{STP} raw biogas with an average methane content of 64 vol%. The raw biogas is temporarily stored in an external biogas storage tank before it is purified from hydrogen sulphide by an activated carbon filter. Afterwards, the purified biogas is upgraded, mainly by a chemical scrubber, into biomethane, but on demand two additional water scrubber units can be operated. Finally, in the compressor station, the biomethane is compressed to a pressure of 250 bar. The compressed biomethane is then used as transportation fuel. Fig. 1 shows an overview plan of the plant.

2.2. On-site measuring approaches

2.2.1. Leakage detection of biogas-bearing plant components

On the first day of the measuring campaign, four teams (Teams A – D) individually performed a leakage search. Each biogas-bearing plant component (digesters, biogas storages, biogas piping, biomethane compressor stations, etc.) was investigated separately by the individual measurement teams. Table 1 lists the different measuring equipment used for leakage detection. Three teams (A, B and C) used an infrared (IR) camera (GF 320, Co. FLIR, Wilsonville, USA), which visualises biogas emitted from a source as a grey-coloured cloud and so enables remote sensing of emission sources, which are otherwise difficult to access. The camera is adjusted to a wavelength range between 3.2 and 3.4 μm, and due to the absorption of infrared radiation in this range by many hydrocarbons some gases, including methane, become visible to the camera. The IR camera has a detection limit of about 8–9 L CH_4 h^{-1} under laboratory conditions (pure CH_4, approx. 2 m s^{-1} wind and 3 m distance) and does not state a gas concentration value (Benson et al., 2006). For this reason, Team C additionally used a portable methane laser (LaserMethane mini gen2, Co. GROWCON, Abingdon, UK) and a portable methane analyser equipped with an IR sensor (BM 2000, Co. Geotech, Leamington Spa, UK) to verify the located leakages. Team D used a portable methane analyser (EX-TEC PM4, Co. Sewerin, Gütersloh, Germany) equipped with a semiconductor (0–22,000 ppm), a catalytic combustion unit (0.0–4.4 vol%) and a thermal conductivity sensor (0–100 vol%).

2.2.2. Emission quantification of leakages from biogas-bearing plant components

After localising leakages, emissions from each individual leakage were quantified by the four teams applying different measuring methods. As not all teams identified the same leakages (see Section 3.1), a shared list of all the identified leakages was made on the second day of the measuring campaign, and these were quantified by all teams, providing they had the required measuring equipment. Table 2 provides an overview of on-site sources quantified by the different teams.

Teams A and B used a high-volume sampling technique, which extracts methane emitted from a leakage together with high amounts of diluting air by means of a sampling hood, a hose and a connected blower (ATmosphère EXplosive (ATEX) proof, Team A, MSX 200-3, GEOVENT A/S, Løgstrup, Denmark; Team B, HVF/200-2EX, Vacumex, Fyn; Denmark). The sampling hoods were customised to the conditions of the individual emission sources. Consequently, the form and dimensions of hoods varied between sources. The gas concentration of the diluted methane emission was sampled continuously and analysed by a photo acoustic detector (Team A, INNOVA 1412, Co. LumaSense Technologies, Santa Clara, USA) or a flame ionisation detector (Team B, Thermo FID, Co. M&A Analysentechnik GmbH, Leverkusen, Germany). Both teams measured the volume flow by analysing the pressure difference with a calibrated orifice (FMU, Co. Lindab GmbH, Bargteheide, Germany) and a differential pressure sensor (2020P7, Co. Digitron,

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