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Determination of methane emission rates on a biogas plant using data from laser absorption spectrometry

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1. Introduction

Fermentation of biodegradable material like energy crops, agricultural residues as well as organic waste became increasingly important during the last years for achievements of sustainable energy generation. Anaerobic fermentation of organic material leads to a production of methane and carbon dioxide. Biogas is generally used to generate electrical and thermal energy. The fermentation of organic material and further utilization of generated heat and electricity can reduce greenhouse gas emissions (De Vries et al., 2012; Scholz et al., 2011).

Recent studies provide indication of high methane emissions of biogas plants, especially fugitive emissions. The amount of emissions depends on the installed facility components, where an open storage tank can be one of the main sources. More noticeable differences in emissions might occur due to misapplied equipment (e.g. leakages or service openings) or due to operation of the plant (Liebetrau et al., 2010). The biogas production efficiency is directly affected by the fugitive emissions (Flesch et al., 2011). The amount of biogas is lost and cannot be used to generate energy. Therefore a measurement method for fugitive emissions is crucial to evaluate the lost potential and to initiate countermeasures.

Common measurement methods for methane have some disadvantages. Methane emissions of particular plant equipment can be measured with complex on spot measurements for example by a flame ionization detector (FID) or a gas camera based on infrared spectral radiometry (Liebetrau, 2011). Those are poorly suitable for measuring total emission rates. In contrast remote sensing measurement methods deliver optically originated data of random

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areas rapidly and do not interact with operational tasks. A measurement method using a combination of an open path tunable diode laser absorption spectrometer (TDLAS) and a micrometeorological method was used to measure fugitive methane emissions from a Canadian biodigester by Flesch et al. (2011). This method was adopted to determine methane emission rates of a biogas plant in Rhineland-Palatinate, Germany.

2. Methods

2.1. Measurement method

An interaction of an open path remote sensing measurement methodology, meteorological measurements and an backward Lagrangian stochastic (bLs) method can provide needed information to quantify the emission rate of a fugitive source, like biogas plants.

Basis for the emission rate calculation is to define an area source that is emitting methane with a constant but unknown rate Q (in g/m^2/s). Meteorological parameters needs to be provided, for example by an ultra sonic anemometer. In a downstream position of the source, the TDLAS measures an integrated line concentration (C_L) between the spectrometer and a retroreflector. The instrument is operating on infrared absorption spectrometry by using Beer–Lambert law. It is recommended to position the concentration measurement 10 times the height of the highest obstacle away, so the plant can be assumed a flat area source (Flesch et al., 2011). A second line concentration upstream the source measures the methane background level in the atmosphere (C_b).

The software WindTrax (Thunder Beach Scientific) was used to calculate the emission rate Q of the source. WindTrax is an inverse dispersion model based on the Monin–Obukhov similarity theory described in Flesch et al. (2004). The model predicts a ratio of the downwind concentration to the emission rate $(C_L/Q)_{sim}$, which depends on the size and shape of the emission source, wind conditions and the concentration sensor position. With this ratio and the measured concentration the methane emission rate can be calculated. The bLs model creates thousands of particle trajectories from each point spaced evenly along the path length of the sensor and tracks them upwind by simulating a mostly natural turbulence dispersion in the atmosphere. The important information out of the back trajectories is their intersections with ground and their corresponding vertical velocities (w_0), especially of those touching the source area. The touchdown velocities are functions of turbulence data, i.e. friction velocity u^*, Obukhov stability length L, surface roughness length z_0 and average wind direction β. Therefore $(C_L/Q)_{sim}$ and as a result the methane emission rate Q_{bLs} are calculated after (McBain and Desjardins, 2005):

$$Q_{bLS} = \frac{C_L - C_b}{(C_L/Q)_{sim}} \qquad (C_L/Q)_{sim} = \frac{1}{P}\sum_{i=1}^{P}\left(\frac{1}{N}\sum\left|\frac{2}{w_0}\right|\right).$$

Whereby P and N represent, respectively, the number of points along the measurement line and the total number of particles released from each point.

2.2. Biogas plant

Measurements were conducted in December 2013 at a biogas plant in Rhineland-Palatinate, Germany. It consists of two main digesters each with a capacity of 2100 m^3. Connected to them are a secondary digester (2700 m^3), an open and a closed digestate storage tank (each 3600 m^3). The plant ferments energy crops and liquid manure to produce biogas, which consists of 52% methane. The produced biogas is partly used in a combined heat and power unit (CHP) on-site and partly carried to a remote CHP. The on-site CHP generates 889 kW$_{el}$ which is fed into the public grid and 883 kW$_{th}$ for on-site thermal use (remote CHP: 526 kW$_{el}$, 558 kW$_{th}$). According to the operator the average biogas production rate amounts to 710 m$_N^3$/h.

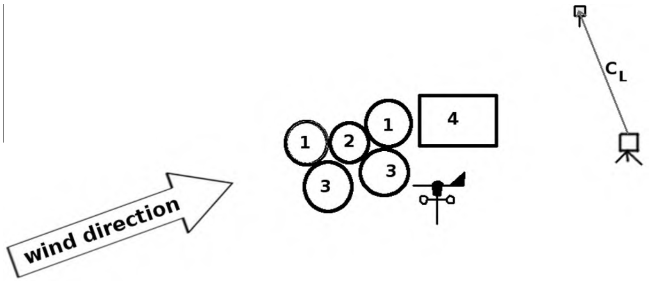

Fig. 1. Experimental setup on site.

2.3. Experimental setup

The experimental setup is shown in Fig. 1. The fugitive emission source was limited to the main digesters (1), secondary digester (2), storage tanks (3) and the on-site CHP unit (4). Methane concentrations were measured with the open-path laser GasFinder 2.0 (Boreal Laser Inc.). The integrated transmitter/ receiver is already adjusted to a wavelength, so it measures specifically methane concentration in ppm·m. The downstream line concentration measuring line was placed 129 m apart the biogas plant. The background concentration was also measured and amounted $c_b = 2.0$ ppm on that day.

Meteorological data were collected with an ultra sonic anemometer situated on the measuring site at a height of 3.6 m. During measuring period defined amounts of biogas were additionally released with an adjustable valve, positioned at the outlet of the secondary digester to the open storage tank. The volume flows were monitored with a vane anemometer and a multifunctional power meter (10 m^3/h for 45 min and 20 m^3/h for 30 min). The modulated gas release resembled a known point source within the assembly of the biogas plant and was included in a second simulation.

3. Results and discussion

Fig. 2 shows the progression of the methane emission rates accruing from the biogas plant in total. The single dots were the resulting emission rates of the biogas plant when the additional gas release was eliminated. In the WindTrax simulation the particle trajectory paths of a known source originate at the release point and are followed in a forward mode. Their intersections with the ground are getting considered and are proportional deducted from the previous emission rate. According to the emission rates different operating conditions could be specified. We regard normal operation (a) as periods where no pressure relief valves were active, no stirring and no flaring occurred. During normal operations the methane emission rates averaged 2.8 g/s, which corresponds to 3.8% of the average methane gas production rate of the biogas plant. Deduced from

$$\dot{m}_{CH_4} = \dot{V}_{biogas} \cdot c_{CH_4} \cdot \rho_{CH_4} = 710\,\mathrm{m_N^3/h} \cdot 0.52 \cdot 0.72\,\mathrm{kg/m_N^3} = 73.6\,\mathrm{g/s}.$$

Flesch et al. (2011) found similar results (3.5%) for a similar experimental setup in winter. The first two peaks could be linked to an open pressure relief valve (c) emitting a great amount of methane (11.8 g/s). This amount was almost four times as high as during normal operations and corresponds to 16.2% of the methane gas production. Wind gusts or excessive gas production and

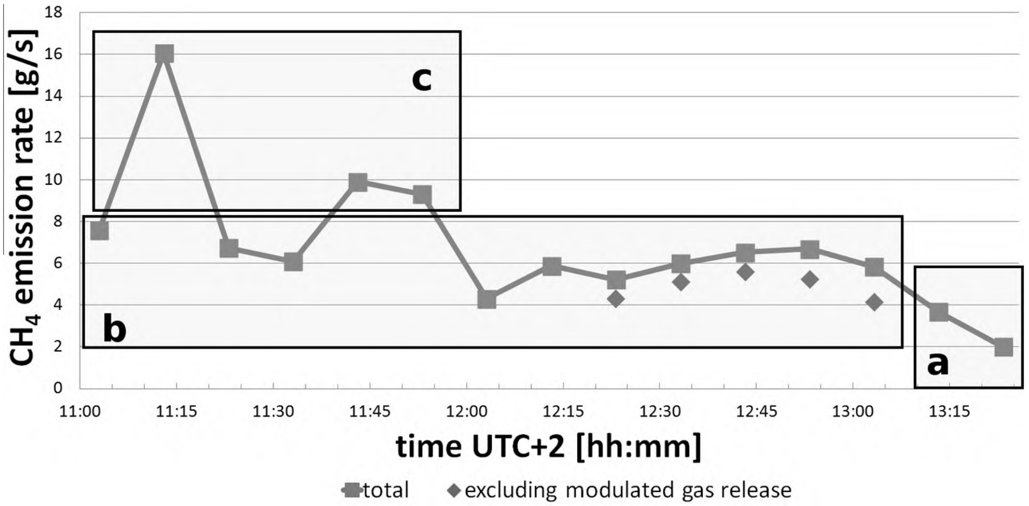

Fig. 2. Methane emission rates of the biogas plant during measuring time.

the resulting higher pressure on the digester cover can cause such pressure relief valve openings. Stirring of the digestate in the storage tanks (b) released the prior anaerobic produced methane (5.5 g/s). Especially stirring in the open digestate storage tank shaped the time curve of the methane emission rate. Furthermore a slight decrease of the methane emission rates was noticeable due to digested residue discharge on that day. Similar observations were made by Van der Zaag et al. (2013) with liquid manure removal at a dairy farm.

The modulated biogas release rate of 10 m^3/h equaled under standard conditions a methane emission rate of 0.9 g/s. Analogously 20 m^3/h equaled a methane emission rate of 1.8 g/s. These amounts replicated the different emission rates between the two performed simulations. Due to the general emission rate fluctuations of a biogas plant, it is hard to determine the accuracy of recovery rates. Several studies to investigate accuracy of the method were already been made and proofed good (Harper et al., 2010). This information was used to demonstrate that a known amount of methane, like from the exhaust gas stream of the CHP, can be considered in the results and it can be focused on the fugitive emissions.

4. Conclusions

Indirect measuring methods do not interact with operational tasks and can therefore be used to measure total methane concentrations during operations or for badly accessible sites by measuring in a defined distance to a biogas plant. The combination of WindTrax and TDLAS data presents a simple and generally available method for monitoring biogas plant operations. The measurement requirements for experimental setup are manageable and the software is user friendly.

Prospectively the method can quantitatively identify leakages of specific components. Determine fugitive methane emissions can initiate measures to improve biogas production efficiency and to reduce green house gas release.

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