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# GAS COLLECTION EFFICIENCY AT TWO DANISH LANDFILLS

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**SUMMARY:** Gas collection efficiency at two adjacent Danish landfills was determined in this study. The average total combined methane (CH<sub>4</sub>) emission from the two sites was 33.3 kg CH<sub>4</sub>/h, quantified by applying a tracer gas dispersion method. The average CH<sub>4</sub> collection rate was 99.5 kg/h and was supplied by landfill operators. The estimated CH<sub>4</sub> oxidation rate was 3.7 and 18.7 kg/h based on assumptions of 10% and 36% CH<sub>4</sub> oxidation, respectively. Gas collection efficiency for the landfills was 66-73%, thereby indicating that a relatively high proportion of the generated CH<sub>4</sub> is being emitted into the atmosphere, and thus there is a need to improve gas collection systems, in order to mitigate CH<sub>4</sub> releases from landfills.

## 1. INTRODUCTION

The disposal of waste, containing organic material, in landfills results in landfill gas (LFG) generation. LFG consists of methane (CH<sub>4</sub>: 55-60%) and carbon dioxide (CO<sub>2</sub>: 40-45%). The global warming potential of CH<sub>4</sub> is 28 times higher than CO<sub>2</sub> (IPCC, 2013). Landfills are one of the main sources of anthropogenic CH<sub>4</sub> released into the atmosphere (Bogner et al., 2008), and these emissions can continue for several decades. If LFG emissions are not mitigated or controlled, they can result in other negative effects apart from global warming, such as explosion or fire hazard, odour and damage to vegetation.

In Denmark, the landfilling of organic waste has been banned since 1997. However, many landfills still continue to generate CH<sub>4</sub>, which can be extracted and used as a renewable energy source to produce heat and electricity. At landfills where the amount of gas or its quality is too low to be utilised, CH<sub>4</sub> is flared or biocovers are designed in order to mitigate emissions. Nonetheless, in spite of gas flaring, utilisation or oxidation systems, a proportion of this CH<sub>4</sub> may be emitted into the atmosphere via slopes, cracks in the landfill cover, leachate collection systems or other areas of weakness.

The efficiency of a gas collection system installed at a landfill is often calculated by dividing the CH<sub>4</sub> collection rate by the total CH<sub>4</sub> production rate, which is determined by modelling. However, the uncertainty of these models can be significant (Scharff and Jacobs, 2006). Thus, field measurements of whole landfill site CH<sub>4</sub> emissions may improve how the efficiencies of installed gas collection systems are assessed. The objective of this study was to quantify CH<sub>4</sub> emissions from two adjacent Danish landfills and determine the gas collection efficiency for these sites.

## 2. MATERIAL AND METHODS

### 2.1 Landfill site description

Odense Nord and Stige Ø landfills are located close to each other in Odense, Denmark. Stige Ø landfill was established in 1967 and received several of the waste types generated in the Odense area, including municipal solid waste, until its closure in 2005. The landfill contains around 7 million tons of waste and soil, and it covers an area of 56 hectares. The Odense Nord landfill received waste from 1994, and it is still in operation. Odense Nord receives different types of waste, including mixed waste, shredder waste, asbestos, polluted soil, garden waste and sludge. In the northern part of the site, composting of garden waste and sludge mixed with straw is carried out. A map of Odense Nord (with its different sections) and Stige Ø landfills is presented in Figure 1.

Gas extraction facilities are installed at Stige Ø and mixed waste cells and shredder waste cells of Odense Nord. There are six pump and regulation modules (MPR-module) at Stige Ø and Odense Nord landfills, each of which is connected to a local power plant, where a gas engine produces electricity and a boiler produces heat.

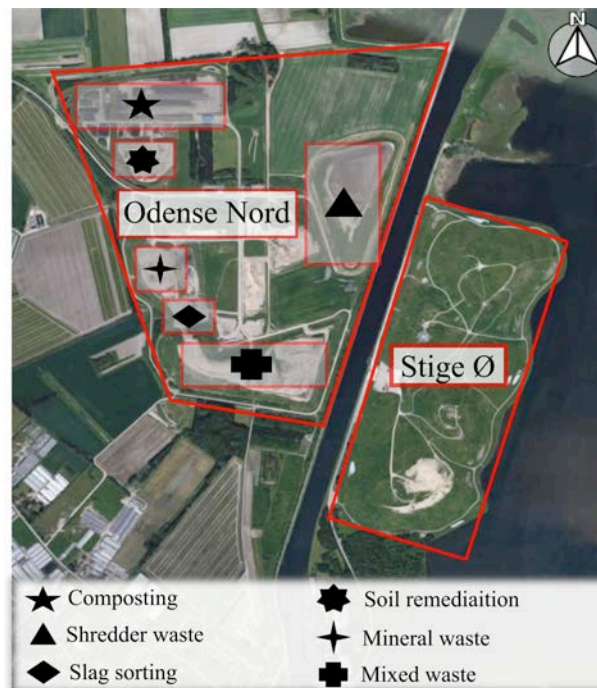


Figure 1. Map of Odense Nord (left) and Stige Ø (right) landfills (Imagery ©2016 Google, Aerodata International Surveys, DigitalGlobe, Map data ©2016 Google)

### 2.2 CH<sub>4</sub> emission measurements

A tracer gas dispersion method was used for quantifying total CH<sub>4</sub> emissions from the two sites. The CH<sub>4</sub> emission was quantified by performing several traverses downwind and perpendicular to the plume from the landfill while measuring the atmospheric concentration of CH<sub>4</sub> and a tracer gas, the latter of which was released continuously at a controlled rate. The

CH<sub>4</sub> emission rate ( $E_{CH_4}$ ) was calculated as a function of the ratio of the integrated cross-plume concentration of the CH<sub>4</sub> emitted to the integrated cross-plume concentration of the tracer gas, as follows:

$$E_{CH_4} = Q_{tracer} \times \frac{\int_{plume\ start}^{plume\ end} C_{CH_4} dx}{\int_{plume\ start}^{plume\ end} C_{tracer} dx} \times \frac{MW_{CH_4}}{MW_{tracer}} \quad (1)$$

where  $Q_{tracer}$  is the release rate of the tracer gas (kg/h),  $C_{CH_4}$  and  $C_{tracer}$  are the concentrations of CH<sub>4</sub> and tracer downwind (ppmv) above the background,  $x$  is the distance across the plume (m) and  $MW_{CH_4}$  and  $MW_{tracer}$  are the molar weights of CH<sub>4</sub> and the tracer gas, respectively. Further details on the method can be found in Mønster et al. (2014).

Acetylene was used as the tracer gas, and its release rate ( $Q_{tracer}$ ) was controlled with calibrated flow meters/regulators (Sho-rate, Brooks Instrument, Holland). Gas concentrations were measured by a C<sub>2</sub>H<sub>2</sub>/CH<sub>4</sub>/H<sub>2</sub>O analyser (G2203, Picarro, Inc., Santa Clara, CA) based on cavity ring-down spectroscopy (CRDS).

Two measurement campaigns were performed (on October 7 and 21, 2016) in order to quantify total CH<sub>4</sub> emissions from the two landfills. The measuring days were chosen in order to assure the separation of CH<sub>4</sub> emissions from the composting facility and the two landfills, by measuring in an east-north-east (ENE) wind direction. Prior to the measurement campaigns, screening was performed in order to identify CH<sub>4</sub> emission hotspots where we could place the tracer gas bottles. Table 1 provides an overview of the measurement details for each campaign.

Table 1. Overview of whole-site CH<sub>4</sub> emission quantification campaigns

Date	Wind direction	Avg. wind speed (m/s)	Avg. Temperature (°C)	Avg. barometric pressure (mbar)	Change in barometric pressure during 6 hours before measurement (mbar/h)	Tracer release points	Number of plume traverses
October 07, 2016	ENE	6	10.8	1024	-0.10	4	15
October 21, 2016	ENE	7	8.0	1015	-0.03	4	11

### 2.3 Gas collection efficiency

Total CH<sub>4</sub> production for the landfills was determined by mass balance, as shown in Eq. 2 (Börjesson et al., 2009):

$$P = E + C + Ox \quad (2)$$

where  $P$  is the total CH<sub>4</sub> production rate (kg/h),  $E$  is the CH<sub>4</sub> emission rate (kg/h),  $C$  is the CH<sub>4</sub> collection rate (kg/h) and  $Ox$  is the CH<sub>4</sub> oxidation rate (kg/h). The CH<sub>4</sub> emission rate ( $E$ ) was determined by applying the tracer dispersion method (section 2.2.). The CH<sub>4</sub> collection rate ( $C$ ) was supplied by the landfill operators. The rate of CH<sub>4</sub> oxidation ( $Ox$ ) was calculated by Eq. 3 (Scheutz et al., 2011):

$$Ox = f_{ox} \left( \frac{E}{1 - f_{ox}} \right) \quad (3)$$

where  $f_{ox}$  is the fraction of oxidised  $CH_4$  (%) and  $E$  is the  $CH_4$  emission rate (kg/h). Two different fractions of oxidised  $CH_4$  ( $f_{ox}$ ) were assumed: 10% (IPCC, 2006; USEPA, 2004) and 36% (Chanton et al., 2009) and correspondingly two  $CH_4$  oxidation rates were calculated and compared. Thus, by having the total  $CH_4$  production rate, it was possible to calculate gas collection efficiency (GCE) as follows:

$$GCE (\%) = \left( \frac{C}{E+C+O_x} \right) \times 100 \quad (4)$$

### 3. RESULTS AND DISCUSSION

#### 3.1 $CH_4$ emission measurements

Figure 2 shows  $CH_4$  and tracer gas plumes measured downwind of the landfills, and Table 2 provides an overview of the measured emission rates from the landfills, composting facility and distinguished section of the landfills, where possible. Emissions from the landfills were 33.5 and 33.0 kg/h on October 07 and 21, respectively.

The measured emissions of 24.5 and 28.0 kg  $CH_4$ /h from the composting facility were higher than the 16.8 kg  $CH_4$ /h from the same composting facility on January 2012 (Mønster et al., 2015). This is most likely due to higher amount of gardening waste in October in comparison to January, and thus more composting activity at the facility.

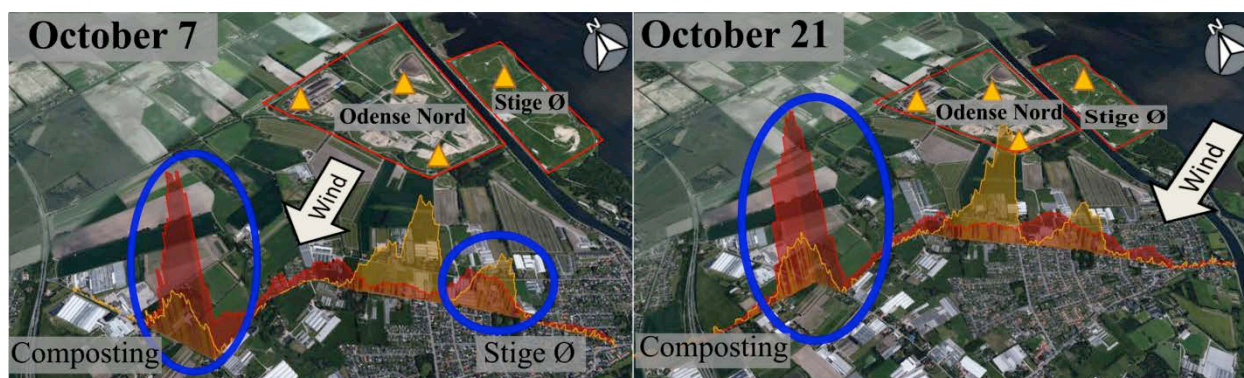


Figure 2.  $CH_4$  (red) and tracer gas (yellow) plumes measured downwind of the landfills. The orange triangles indicate the tracer gas release locations. The blue circles show emissions from the composting facility or distinguished sections of the landfills (Imagery ©2016 Google, Aerodata International Surveys).

Table 2.  $CH_4$  emissions from the landfills and composting facility. Digits given in brackets represent standard deviation.

Date	Both landfills + composting facility emissions (kg $CH_4$ /h)	Composting facility emissions (kg $CH_4$ /h)	Both landfills emissions (kg $CH_4$ /h)	Distinguished landfill section emissions (kg $CH_4$ /h)
October 07, 2016	58.0 (5.6)	24.5 (5.1)	33.5 (3.8)	Stige Ø = 12.7 (0.85)
October 21, 2016	61.0 (4.2)	28.0 (2.9)	33.0 (2.3)	-

Comparing the measured CH<sub>4</sub> emissions for these two landfills with 14 other Danish landfills measured by Mønster et al. (2015), it was observed that those in this study were higher than for most Danish landfills. However, the measured CH<sub>4</sub> emissions were significantly lower than CH<sub>4</sub> emissions measured at US sites (Czepiel et al., 2003; Mosher et al., 1999) and some Swedish facilities (Börjesson et al., 2009).

### 3.2 Calculation of gas collection efficiency

Table 3 shows the CH<sub>4</sub> collection rate, measured CH<sub>4</sub> emission rate, estimated CH<sub>4</sub> oxidation rate and calculated efficiency of the gas collection system installed at the landfill. The average combined CH<sub>4</sub> collection rate was 99.5 kg/h. The estimated CH<sub>4</sub> oxidation rates were 3.7 and 18.7 kg/h based on  $f_{ox}$  of 10% and 36%, respectively. The significant difference in CH<sub>4</sub> oxidation rate by varying the  $f_{ox}$  value indicated the importance of site-specific determinations of CH<sub>4</sub> oxidation rates for more precise gas collection efficiency ratings.

Gas collection efficiency for the landfills was 66-73%, which is comparable to the reported gas collection efficiency of 69-79% found by Lohila et al. (2007), though it is lower than the 90% reported by Mosher et al. (1999). Mønster et al. (2015) showed that Danish landfills with gas collection and recovery systems had a recovery efficiency of 41 to 81%. The collection efficiency in our study indicates that there is high potential for optimising the gas collection systems at the two landfills, which could result in an environmentally beneficial lower rate of CH<sub>4</sub> released into the atmosphere. Moreover, it would result in greater CH<sub>4</sub> collection and thus higher heat and electricity production, which makes the landfills more economically viable.

Table 3. CH<sub>4</sub> collection, emission, oxidation and gas collection efficiency of the landfills.

Date	CH <sub>4</sub> collection rate (kg/h)	CH <sub>4</sub> emission rate (kg/h)	CH <sub>4</sub> oxidation rate (kg/h)		Gas collection efficiency (%)	
			A <sup>(a)</sup>	B <sup>(b)</sup>	A <sup>(a)</sup>	B <sup>(b)</sup>
October 07, 2016	101	33.5	3.7	18.8	73	66
October 21, 2016	98	33.0	3.7	18.6	73	66
Average	99.5	33.3	3.7	18.7	73	66

<sup>(a)</sup> It was calculated based on  $f_{ox} = 10\%$

<sup>(b)</sup> It was calculated based on  $f_{ox} = 36\%$



#### 4. CONCLUSIONS

An average combined CH<sub>4</sub> emission rate of 33.3 kg CH<sub>4</sub>/h was measured at two Danish landfills. Composting activities resulted in an emission rate of 26.3 kg CH<sub>4</sub>/h. The estimated landfill CH<sub>4</sub> oxidation rates were 3.7 and 18.7 kg/h, assuming methane oxidation fractions of 10% and 36%, respectively. The significant difference in the CH<sub>4</sub> oxidation rate obtained when varying the oxidation fraction indicated the importance of site-specific determinations of the CH<sub>4</sub> oxidation rate for a subsequently more precise assessment of gas collection efficiency. Gas collection efficiency was 66-73% and indicated that a relatively high proportion of generated CH<sub>4</sub> is being emitted into the atmosphere, and thus there is a need to improve the gas collection system.

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