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Validation of a simple model to predict the performance of methane oxidation systems, using field data from a large scale biocover test field

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ABSTRACT

On a large scale test field (1060 m^2) methane emissions were monitored over a period of 30 months. During this period, the test field was loaded at rates between 14 and 46 g CH_4 m^{-2} d^{-1}. The total area was subdivided into 60 monitoring grid fields at 17.7 m^2 each, which were individually surveyed for methane emissions and methane oxidation efficiency. The latter was calculated both from the direct methane mass balance and from the shift of the carbon dioxide - methane ratio between the base of the methane oxidation layer and the emitted gas. The base flux to each grid field was back-calculated from the data on methane oxidation efficiency and emission. Resolution to grid field scale allowed the analysis of the spatial heterogeneity of all considered fluxes. Higher emissions were measured in the upslope area of the test field. This was attributed to the capillary barrier integrated into the test field resulting in a higher diffusivity and gas permeability in the upslope area. Predictions of the methane oxidation potential were estimated with the simple model Methane Oxidation Tool (MOT) using soil temperature, air filled porosity and water tension as input parameters. It was found that the test field could oxidize 84% of the injected methane. The MOT predictions seemed to be realistic albeit the higher range of the predicted oxidations potentials could not be challenged because the load to the field was too low. Spatial and temporal emission patterns were found indicating heterogeneity of fluxes and efficiencies in the test field. No constant share of direct emissions was found as proposed by the MOT albeit the mean share of emissions throughout the monitoring period was in the range of the expected emissions.

1. Introduction

Methane oxidation systems (MOS) were shown to be capable of remediating residual methane fluxes from landfills following the period of technical treatment and are considered an important tool of secondary control of landfill methane emissions (Bogner et al., 2007). Various studies have been carried out to quantify the methane oxidation capacity of soils under different conditions in the laboratory and on-site (overview in (Scheutz et al., 2009). Optima for environmental conditions (Park et al., 2009; Scheutz and Kjeldsen, 2004; Stein and Hettiaratchi, 2001)) and recommendations regarding the employed soil material (LAGA Ad-hoc AG "Deponietechnik", 2011) were derived. However, especially for methane oxidation covers (also called biocovers) several problems exist regarding on-site quantification of performance: (1) gas generation and therefore flux to the cover is usually not known; (2) microbial communities are a dynamic component of soils, on the one hand capable of adaptation to changing environmental conditions and on the other hand prone to environmental stresses like for example drought, extreme temperatures or low nutrient availability. The result is a high temporal variability of emissions (Rachor et al., 2013; Tecle et al., 2009). (3) Due to inhomogeneity of the soil with respect to its physical parameters like bulk density, aggregate structure or moisture distribution and corresponding properties such as air-filled porosity, diffusivity and gas permeability, the spatial pattern of substrate delivery to the microorganisms and of environmental conditions vary. Hence, oxidation rates are also subject to high spatial variability (Bogner et al., 1997; Rachor et al., 2013; Röwer et al., 2011; Tecle et al., 2009). Realistic assessment of larger areas requires an intensive measurement effort with a high areal coverage.

To improve knowledge of the behavior of field scale MOS a test field intended to simulate a methane oxidation cover was constructed in The Netherlands on a site of NV Afvalzorg and monitored about monthly over a period of 30 months. The test field

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was loaded with methane up to 56 g m^{-2} d^{-1}. Sites with a gas generation of up to 35 g m^{-2} d^{-1} are considered suitable for methane oxidation application in the view of the operator NV Afvalzorg. Hence the load to the test field was above the expected loads in real application. For this study, retrieved data was compared to the predictions of the application model *Methane Oxidation Tool* (*MOT*, Gebert et al., 2011c) designed for the estimation of efficiencies of MOS. The purpose was to test whether the model assumptions on the environmental process drivers (air-filled porosity, temperature, water tension) and on the share of the load to the cover soil bypassing the soil as direct emissions (i.e. hotspot-emissions) result in realistic predictions of MOS efficiencies. An additional focus was set on the spatial variability of oxidation efficiencies.

2. Material and methods

2.1. Setup and operation of test field

The test field was situated on a 1:5 sloped edge of a landfill in the northwest of The Netherlands. The field had a size of 1060 m^2 and was integrated into the landfill top cover but separated from the waste body by a high density polyethylene (HDPE) membrane so that only the purposely injected gas entered the test field. Gas injection was realized by six inlet ports situated on the HDPE base sealing within the catchment area that was built to monitor the water infiltration regime of the test field (Figs. 1 and 2). The catchment was delimited with a 40 cm HDPE border welded perpendicularly to the base sealing. The gas supplied to the field at a controllable rate was extracted from two nearby gas wells and monitored with respect to gas quality and quantity and the data were logged in an interval of 10 min. During the investigation period, the inlet flux was varied between 0.7 and 2.6 m^3 CH_4 h^{-1}, corresponding to a nominal load to the test field of 10–57 g CH_4 m^{-2} d^{-1}, assuming even spatial distribution of the base flux. Three flux levels were investigated: 37.8 g CH_4 m^{-2} d^{-1} ± 8.4 from August 2012 until July 2013, 13.7 g CH_4 m^{-2} d^{-1} ± 2.1 from February 2014 until May 2014 and 46.4 g CH_4 m^{-2} d^{-1} ± 8.3 from August 2014 until February 2015 (Fig. 5).

The investigated MOS consisted of a capillary barrier (capillary block: 20 cm gravel (2–8 mm), capillary layer: 30 cm sand (1–2 mm)) and a methane oxidation layer (topsoil: 20 cm loam (according to *World reference base for soil resources* (WRB) (FAO, 2014): L), subsoil: 80 cm loamy sand (WRB: SL) (Fig. 1). The

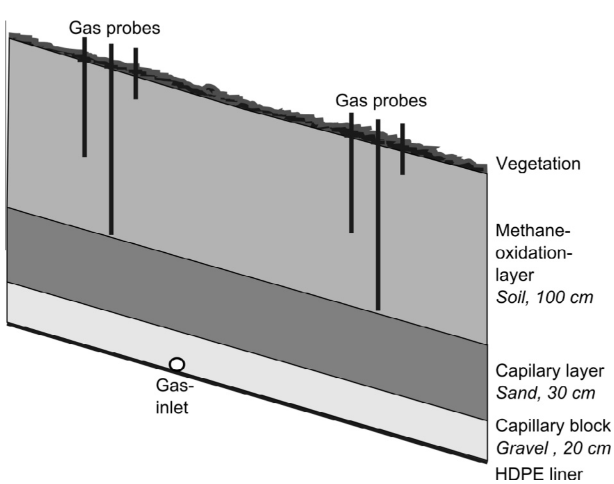

Fig. 1. Setup of test field, cross section.

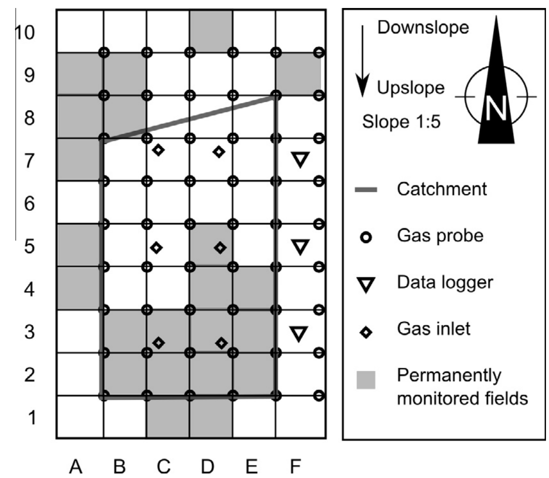

Fig. 2. Top view of test field. A1 to F10: grid fields for emission and soil gas concentration measurement. Grid size is 4.25 m × 4.25 m. Figure shows sampling scheme employed from August 2012 to July 2013: shaded fields monitored in each campaign, one third of white fields monitored per rotation every third campaign.

oxidation layer was initially constructed with a long stick excavator to avoid soil compaction. In July 2013 the test field was reconstructed. The upper 60 cm of the field were excavated and refilled using a bulldozer instead of a long stick excavator. This was done to achieve a higher degree of compaction and to assess the effects of standard construction practice on the relevant soil parameters and on system performance.

The capillary block was meant to function as gas distribution layer, distributing the gas over the entire base area of the test field before it moves upwards evenly through the oxidation layer.

On the surface of the test field a grid was marked permanently with pegs. The grid fields had a size of 4.25 m × 4.25 m. The grid was used to ensure a consistent positioning of the static chamber used for the emission measurement (see Section 2.2, Fig. 2). Also, the soil gas probes were aligned according to the grid (see Section 2.3).

In order to assess the soil environmental parameters relevant for the methane oxidation process, soil moisture (EC5, Decagon) and soil temperature probes (Pt1000) were installed 40 cm below surface in one downslope, one midslope and one upslope position (Fig. 2). Data of midday of each campaign were averaged from down-, mid- and upslope probe.

2.2. Measurement of emissions and campaigning strategy

Emissions were measured using a large static chamber. The quadratic chamber had a base area of 17.7 m^2 and a volume of 8.8 m^3. It was constructed from an aluminum frame covered with aluminum coated plastic foil. Two fans inside of the chamber were mixing the air during the measurement. Gas was sampled continuously through 18 evenly distributed tubes and the change in methane concentration within the chamber over time was detected and recorded with a mobile flame ionization detector ((FID) Toxic Vapor Analyzer, Thermo Scientific, detection limit for methane: 0.25 ppm). Carbon dioxide concentration was recorded using a non-dispersive infrared (NDIR)-sensor (TSI, IAQ-CALC, Model 7525, detection limit for carbon dioxide 1 ppm) sampling the same gas stream as did the FID. Time of enclosure was four minutes. Details on the chamber setup and method validation are given in Geck et al. (2016). The grid fields covered by emission measurements were selected after a campaign in which all 60 grid fields of 4.25 m × 4.25 m were measured. The fields accounting for 90% of the total methane emission were selected to be measured in