Simulation model for gas diffusion and methane oxidation in landfill cover soils

Alex De Visscher, Ghent University, Coupure links 653, B–9000 Gent, Belgium, alex.devisscher@rug.ac.be
Oswald Van Cleemput, Ghent University, Coupure links 653, B–9000 Gent, Belgium, oswald.vancleemput@rug.ac.be

Abstract

A simulation model was developed that describes non-Fickian diffusion, CH4 oxidation and methanotrophic growth in a landfill cover soil. The model was calibrated with published laboratory data. Application of the model to real landfill conditions, accounting for the flux variability, led to a tentative year-round average CH4 oxidation efficiency estimate of about 30% for a sandy loamy soil covering a municipal solid waste landfill producing 105 g CH4 m–2 d–1.

Introduction

As inventories of CH4 emissions from landfills improve, oxidation of CH4 in landfill cover soils increasingly becomes an important source of uncertainty. A reliable simulation model for this process would substantially reduce this uncertainty. This contribution reports the development of such a model.

Mathematical approach

Basis of the simulation model is a transient mass balance across an infinitesimal soil layer, which leads to the following equation:

$$\varepsilon \frac{\partial y_i}{\partial t} \frac{P}{RT} = \rho_{DB} r_i - \frac{\partial N_i}{\partial z}$$  \hspace{1cm} (1)

with $\varepsilon$ the air-filled pore space, $P$ the absolute pressure (Pa), $R$ the universal gas constant (8.31451 J mol⁻¹ K⁻¹), $T$ the absolute temperature (K), $t$ the time (s), $N_i$ the flux of component $i$ (mol m⁻² soil s⁻¹; positive in the case of a downward flux), $y_i$ the mole fraction of component $i$, $z$ the depth ($z = 0$ m at the soil surface), $\rho_{DB}$ the dry bulk density of the soil (kgsoil DW m⁻³ soil), and $r_i$ the reaction rate of compound $i$ (mol kg⁻¹ soil DW s⁻¹). Landfill gas diffusion is a non-Fickian gas diffusion problem, as it involves a four-component gas mixture (CH4, CO2, O2 and N2: Ar was not accounted for). Therefore, the Stephan-Maxwell equations were used for the calculation of the gas flux. Applied to a soil matrix, these equations can be written as:

$$-\frac{P}{RT} \frac{\partial y_i}{\partial z} = \sum_{j=1}^{4} \frac{N_i y_j - N_j y_i}{D_{soil,ij}}$$  \hspace{1cm} (2)
with $D_{\text{soil},ij}$ (m$^3$ gas m$^{-1}$ soil s$^{-1}$ or simply m$^2$ s$^{-1}$) the binary diffusion coefficient of a mixture of gases $i$ and $j$ in a soil matrix. For the reaction rate the following kinetic equation was used:

$$r_{CH_4} = \frac{-V_{\text{max}} y_{\text{CH}_4}}{K_m + y_{\text{CH}_4}} - \frac{y_{O_2}}{K_{O_2} + y_{O_2}}$$

(3)

The model was calibrated to laboratory data of De Visscher et al. (1999). More details are given in a paper under review (De Visscher & Van Cleemput, 2002).

Since the model is one-dimensional, the model by itself cannot account for spatial variation of the landfill gas flux. Therefore, the model was applied to a range of landfill gas fluxes entering the soil cover from underneath. The resulting methane oxidation predictions are then integrated assuming a Gaussian distribution of the landfill gas flux entering the cover soil. This calculation was performed for three sets of environmental conditions: representing summer, spring/autumn, and winter, respectively. The result is shown in Figure 1.

**Figure 1** Simulated gross methane flux distribution (thick solid line), simulated net methane flux distribution (thin solid lines), and simulated methane oxidation distribution (dotted lines) in a landfill cover soil under Belgian climatic conditions

**Conclusion**

The model predicts a pronounced spatial and seasonal variation of the methane flux leaving the landfill cover. On average, the model predicts a methane oxidation of 33 g CH$_4$ m$^{-2}$ d$^{-1}$, for a cover soil receiving 105 g CH$_4$ m$^{-2}$ d$^{-1}$ on average.

**References**
