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

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Abstract

A simulation model was developed that describes non-Fickian diffusion, CH_4 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 CH_4 oxidation efficiency estimate of about 30% for a sandy loamy soil covering a municipal solid waste landfill producing 105 g CH_4 m^{-2} d^{-1}.

Introduction

As inventories of CH_4 emissions from landfills improve, oxidation of CH_4 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:

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

with ε 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 $m^{-2}{}_{\mathrm{soil}}$ 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), ρ_{DB} the dry bulk density of the soil ($\mathrm{kg_{soil\ DW}}$ $\mathrm{m^{-3}{}_{soil}}$), and r_i the reaction rate of compound i (mol $\mathrm{kg^{-1}{}_{soil\ DW}}$ s^{-1}). Landfill gas diffusion is a non-Fickian gas diffusion problem, as it involves a four-component gas mixture (CH_4, CO_2, O_2 and N_2: 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:

$$-\frac{P}{RT} \frac{\partial y_i}{\partial z} = \sum_{\substack{j=1 \\ j \neq i}}^{n} \frac{N_i y_j - N_j y_i}{D_{\mathrm{soil},ij}} \qquad (2)$$

with $D_{\mathrm{soil},ij}$ ($\mathrm{m^3{}_{gas}\ m^{-1}{}_{soil}\ s^{-1}}$ or simply $\mathrm{m^2\ s^{-1}}$) 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:

$$r_{CH_4} = -\frac{V_{\max}\, y_{\mathrm{CH_4}}}{K_{\mathrm{m}} + y_{\mathrm{CH_4}}} \cdot \frac{y_{\mathrm{O_2}}}{K_{\mathrm{O_2}} + y_{\mathrm{O_2}}} \qquad (3)$$

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.

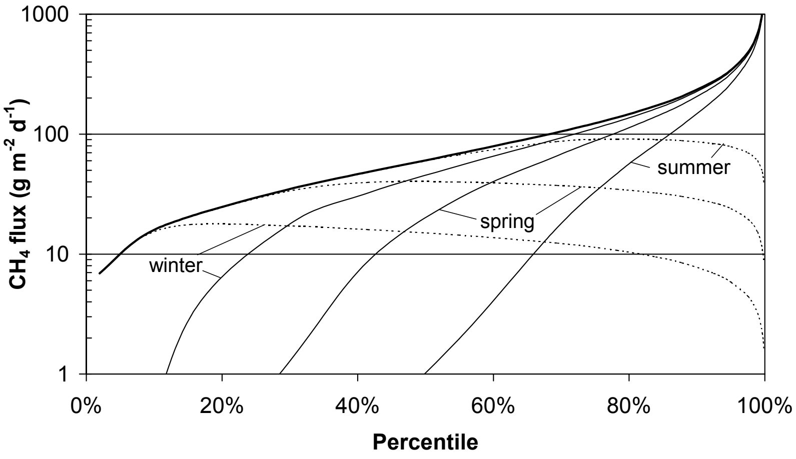

Figure 1 Simulated gross methane flux distribution (thick solid line), simulated net methane flux distribution (thin solid lines), and simulated methane oxidation distribution (dotted lines) in a landfill cover soil under Belgian climatic conditions

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 $\mathrm{CH_4\ m^{-2}\ d^{-1}}$, for a cover soil receiving 105 g $\mathrm{CH_4\ m^{-2}\ d^{-1}}$ on average.

References

De Visscher A., Thomas D., Boeckx P. & Van Cleemput O. (1999) Methane oxidation in simulated landfill cover soil environments. *Environ. Sci. Technol.* **33**, 1854–1859.

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