Université de Marne-La-Vallée

Cemagref d'Antony

Modeling Thermal Behavior of Bioreactor Landfills Before Leachate Recirculation

Shabnam Gholamifard, Robert Eymard

and Christian Duquennoi

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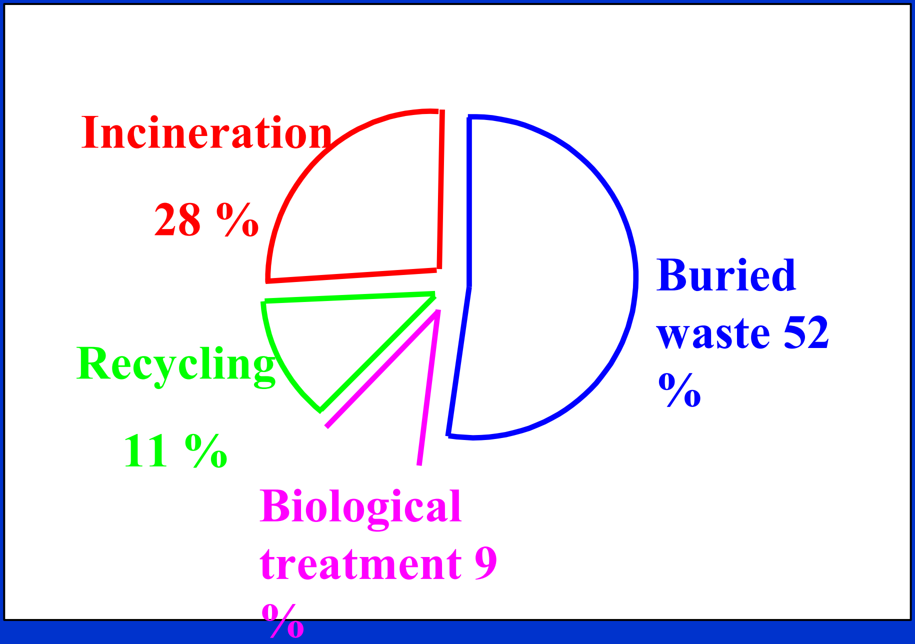
Outline

- Introduction to bioreactor landfills
  - Objectives of modeling
- Mathematical model
  - Biological model of degradation and gas production
  - Numerical techniques
    - Finite Volumes method
- Numerical results
  - Application to a bioreactor landfill
- Conclusions and perspectives

Introduction to bioreactor landfills

Waste production in France (Ademe 2002): 46 Mt /y



Landfill: A site for the disposal of waste materials (paper, kitchen waste, textile, wood,…) by burial

Introduction to bioreactor landfills

What is a Bioreactor Landfill?

A landfill site which uses enhanced microbiological treatments to:

- **Accelerate degradation rate**
- **Reduce the time of landfill stabilization**

The most common method: <u>Leachate</u> recirculation

Waste jus!

Objectives of modeling

- Predict and control the gas and leachate production
- Study the biological and thermal behavior
    - effects of saturation and temperature
- Optimize the leachate injection process
- Minimize the degradation and stabilization time

Optimize the time and cost of monitoring

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Mathematical model

Two-phase flow model

- **Mass Conservation**

$$\frac{\partial m_i}{\partial t} + \nabla.\left(\rho_i U_i\right) = 0 \qquad m_l = \phi\, S\, \rho_l \;,\; m_g = \phi\,(1\text{-}S)\,\rho_g$$

Darcy law

- **Energy Conservation**

Mass entropy

Heat production term

$$T\frac{d\eta}{dt} + \sum_{p=l,v} g_p \frac{dm_p}{dt} = -\nabla.(h_p \rho_p v_p) - \nabla.\, q + \alpha$$

Free enthalpy

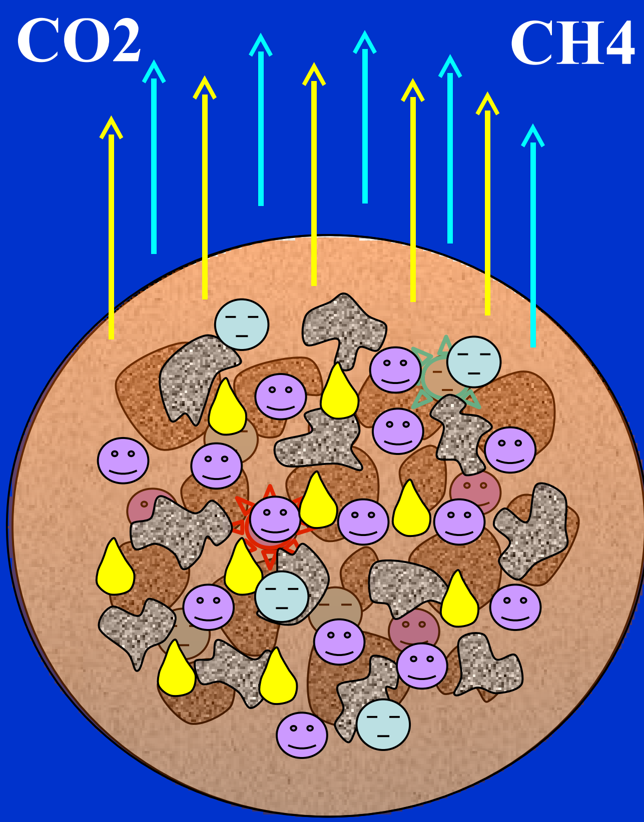
Mass enthalpy

Heat flow defined by Fourier's Law $q = -\lambda \nabla T$

Mathematical model- Assumptions

- The landfill: a three-phases porous medium
- The solid phase: non-deformable
- The fluid phases: immiscible
- Darcy's law: for both fluid phases
- Thermal radiation: neglected
- Thermal equilibrium

Biological model



Biological model

Hydrolysis of solid substrate:

$$\frac{dA}{dt} = -\sum_{i=1}^{3}\left[A_i.\lambda_i(T).fs\right]$$

Volatile Fatty Acid:

$$\frac{dA_S}{dt} = -\beta\frac{dA}{dt} - \mu_{App}(T).gs.\left(\frac{A_S}{K_{S_A} + A_S}\right).X - \alpha_A.q\frac{dA_s}{dZ}$$

Biomass:

$$\frac{dX}{dt} = Y.\left(\underbrace{\mu_{App}(T)}_{Birth}.gs.\frac{A_S}{K_{S_A} + A_S}.X\right) - \underbrace{K_d(T)}_{Decay}X - \alpha_X.q\frac{dX}{dZ}$$

Biogas:

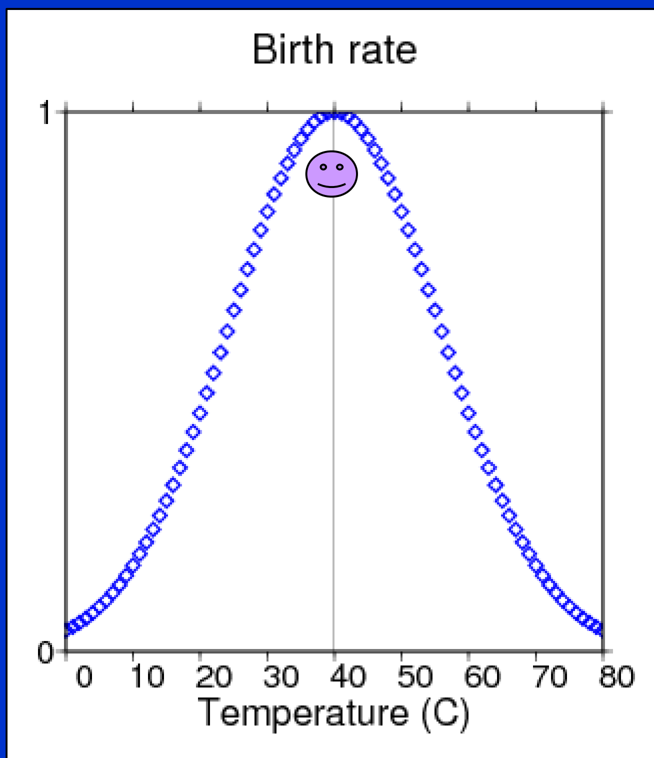
$$\frac{dB}{dt} = (1-Y)\mu_{App}(T).gs.\left(\frac{A_S}{K_{S_A} + A_S}\right).X$$

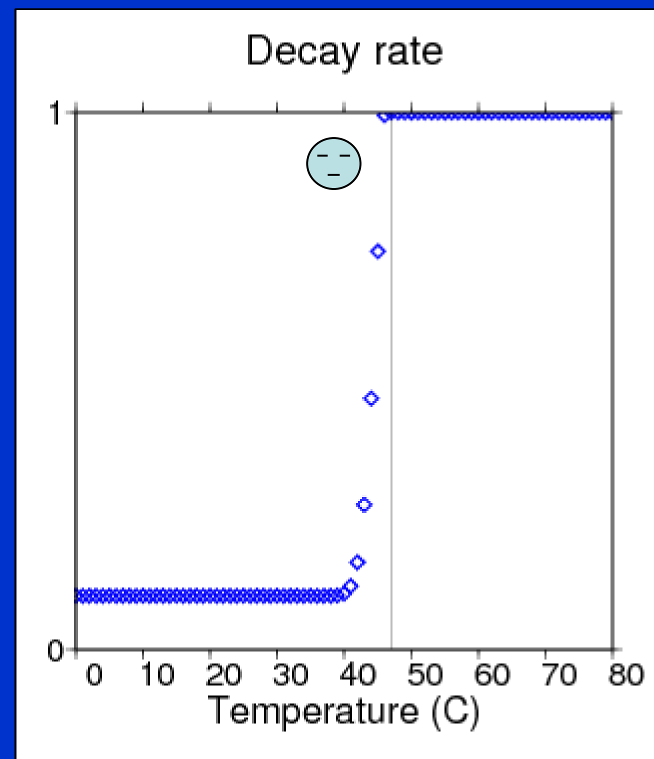
Heat:

$$\alpha_q = \beta\frac{H_{hyd}}{M_{VFA}}.\frac{dA}{dt} + \frac{H_{meth}}{M_{meth}}.\frac{\alpha_b}{2}$$

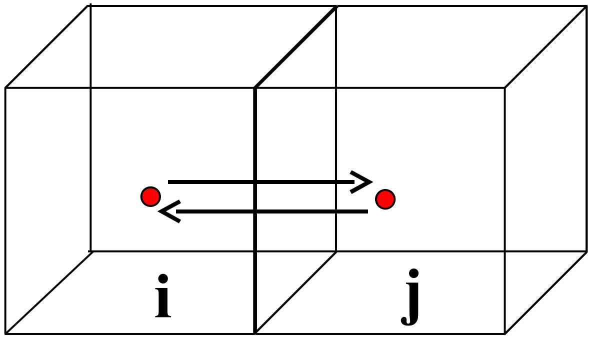
Biological model

$$\frac{dX}{dt} = Y.\left(\underbrace{\mu_{App}(T)}_{Birth}.gs.\frac{A_S}{K_{S_A} + A_S}.X \right) - \underbrace{K_d(T)}_{Decay}X - \alpha_X.q\frac{dX}{dZ}$$





Numerical Techniques- Finite Volumes Method



$$F^{n}_{i,j} = -F^{n}_{j,i}$$

$$V_i \frac{m^{n+1}_{Pi} - m^{n}_{Pi}}{t^{n+1} - t^{n}} + \sum_{i|j} F^{n+1}_{wij} = 0$$

Heat Production

$$V_i \left[T^{n+1}_i \frac{\eta^{n+1}_{hi} - \eta^{n}_{hi}}{t^{n+1} - t^{n}} + \sum_{P=l,g} g^{n+1}_{P_i} \frac{m^{n+1}_{Pi} - m^{n}_{Pi}}{t^{n+1} - t^{n}} \right] + \sum_{i|j} F^{n+1}_{hij} = \overline{Q}^{n+1}_i$$

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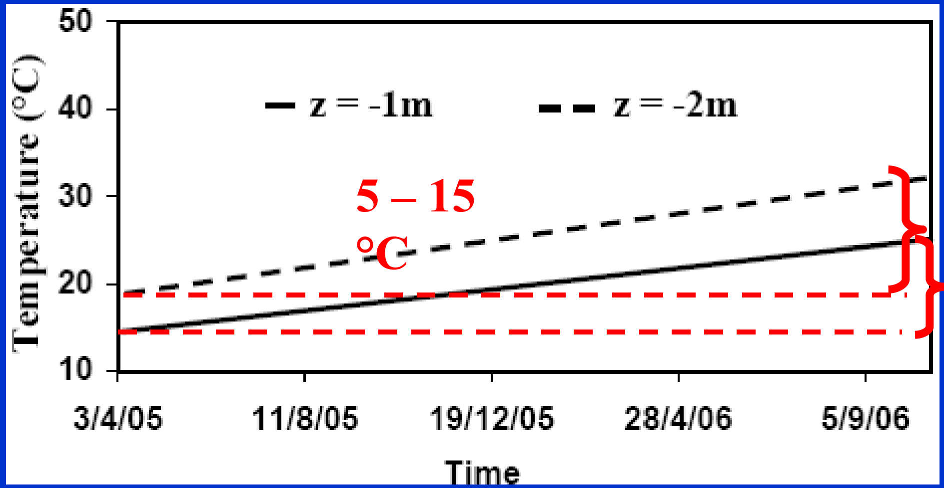
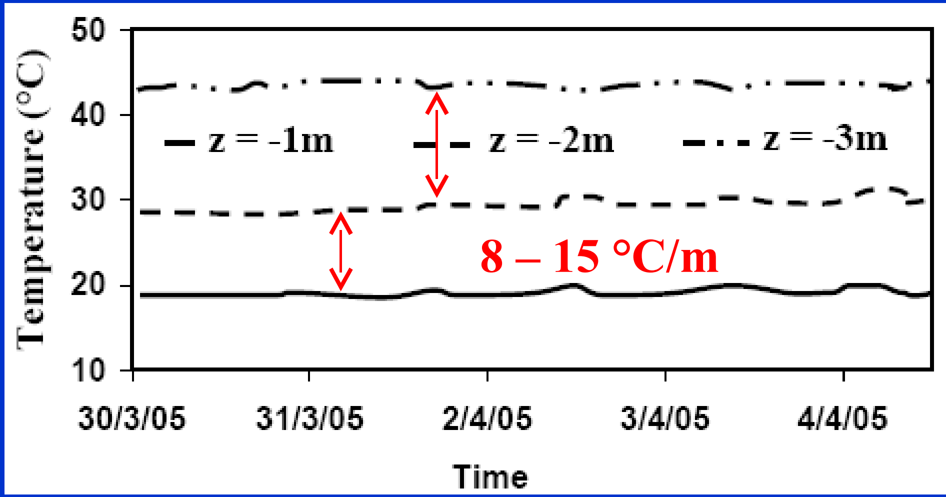
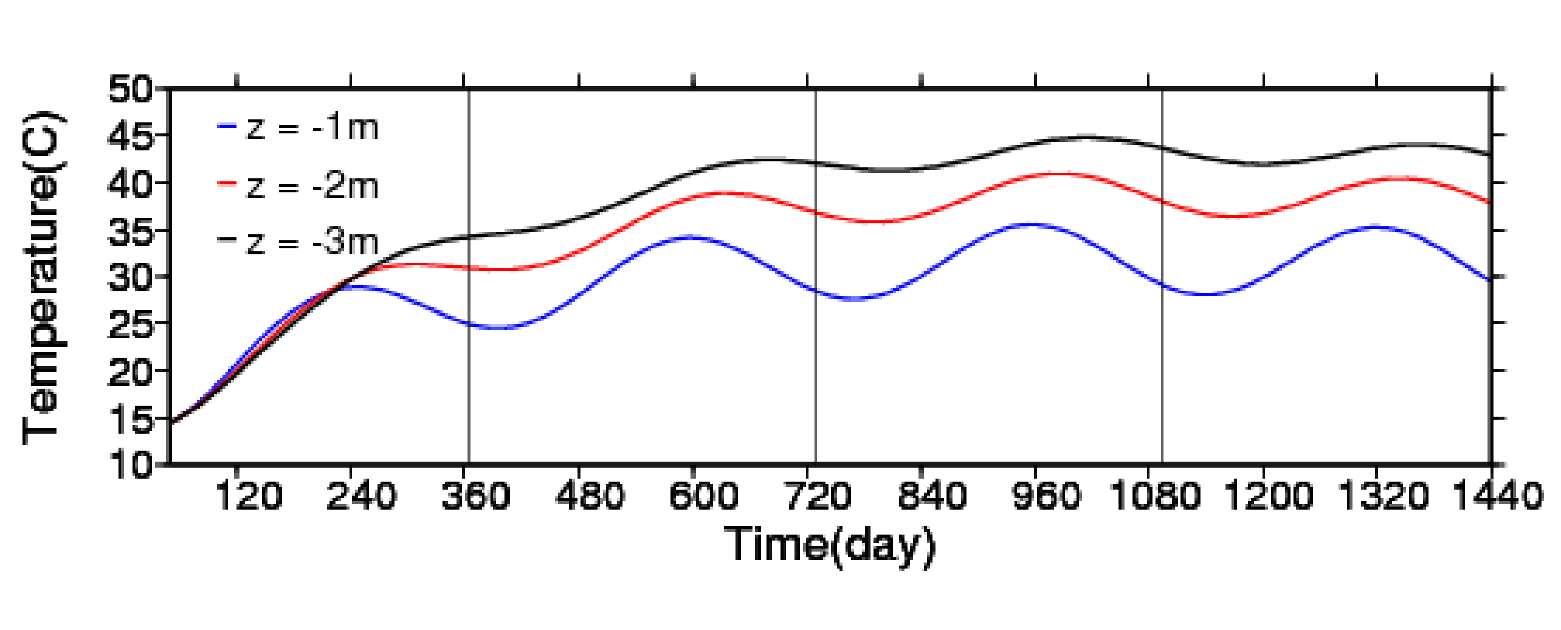
Numerical results- Site observations

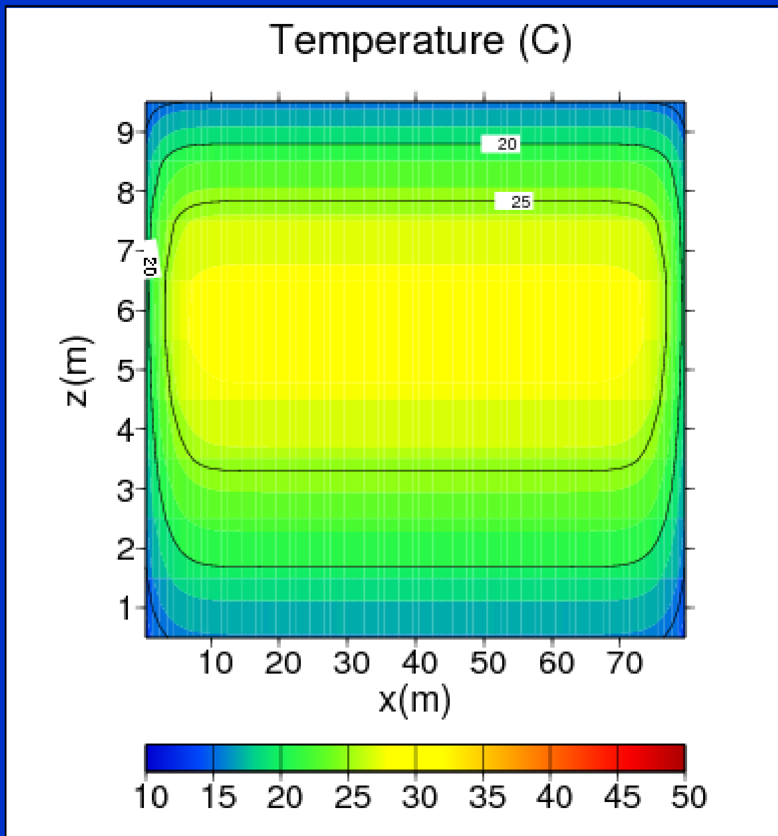




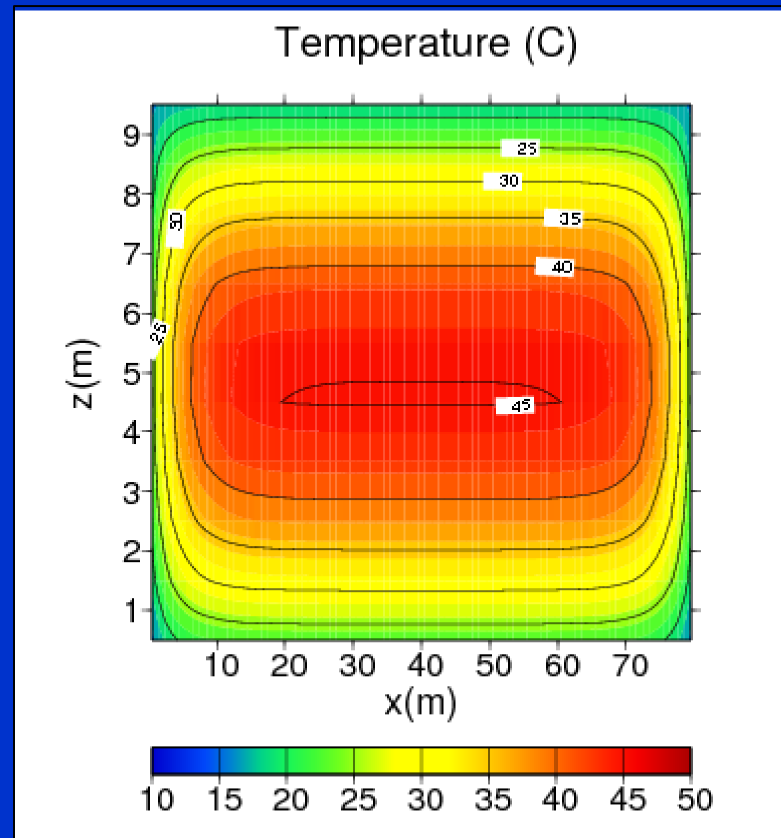
Numerical results



Numerical results



1st year



4th year

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Conclusion

- This model is able to reproduce an appropriate thermal behavior
- The stable thermal condition is a result of:
  - bacterial growth and decay,
  - hydrolysis as a function of degradation kinetics,
  - inhibition of hydrolysis and methane production,
  - external temperature and seasonal changes.

Perspective

- **Validate the model by additional field and laboratory experiments**
- **Study the biological behavior of bioreactor landfills with and without leachate recirculation**

Thanks for your attention!

Shabnam GHOLAMIFARD

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