Numerical modeling of the long term behavior of Municipal Solid Waste in a landfill

Promoteur : Frédéric Collin

30th of January 2015
Julien Hubert
SUMMARY OF THE PRESENTATION

- Introduction to the waste management issue
- THBCM multi-physics model
  - Hydraulic model
  - Bio-chemo model
  - Thermal model
  - Mechanical model
- Test simulation and results
- Conclusion
WASTE MANAGEMENT ISSUE

- Waste production $\rightarrow \{\text{Demographic explosion} \rightarrow \text{Over – Consumption}\$

- It has to be taken care of:

- One of the key point of the waste management issue

- Objective: optimal post closure management
SUMMARY OF THE PRESENTATION

- Introduction to the waste management issue

- THBCM multi-physics model
  - Hydraulic model
  - Bio-chemo model
  - Thermal model
  - Mechanical model

- Test simulation and results

- Conclusion
HYDRAULIC MODEL

- MSW behave like an unsaturated soil:

\[
\frac{\partial (\rho_w n S_{r,w})}{\partial t} + \text{div} (\rho_w f_w) = Q
\]

\(f_w\) is the Darcy’s flow given by the following equation:

\[
f_w = - \frac{k_w(S_{r,w})}{\mu_w} (\text{grad}(p_w) + \rho_w \cdot g \cdot \text{grad}(y))
\]
# Hydraulic Model

Relative permeability and water retention curves (van Genuchten):

<table>
<thead>
<tr>
<th>Relative permeability</th>
<th>Water retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{\text{rel}} = \sqrt{S_{r,w}} \left[ 1 - \left( 1 - S_{r,w} \frac{1}{m_{\text{vG}}} \right)^{m_{\text{vG}}} \right]^2 )</td>
<td>( S_{r,w} = S_{\text{res}} + (S_{\text{sat}} - S_{\text{res}}) \left[ \left( 1 + \frac{p_{c}}{\alpha} \right)^{n_{\text{vG}}} \right]^{-m_{\text{vG}}} )</td>
</tr>
</tbody>
</table>

![Graph of Relative Permeability vs Saturation Level](image1.png)

![Graph of Water Retention vs Capillary Pressure](image2.png)
**Bio-Chemical Model**

- Can be split into two main stages:
  - Aerobic stage $\Rightarrow$ neglected
  - Anaerobic stage

It is assumed it can be simplified:

- Organic Content ($\text{Org}$)
- Hydrolysis & acidogenesis
- Volatile Fatty Acid ($c$)
- Acetogenesis & methanogenesis
- Methanogen Biomass ($m$)
- Methanogen decay
**Bio-Chemical Model**

- McDougall's formulation:
  - **Hydrolysis and acidogenesis**
    \[ r_g = b\theta_e \phi P \]
  - **Acetogenesis and methanogenesis**
    \[ r_j = \frac{k_0 c}{k_{MC} + c} m \]
    \[ r_h = \frac{r_j}{Y} \]
  - **Methanogen decay**
    \[ r_k = k_2 m \]
**Bio-Chemical Model**

- McDougall's formulation:
  - Hydrolysis and acidogenesis
    \[ r_g = b \theta_e \phi P \]
  - Acetogenesis and methanogenesis
    \[ r_j = \frac{k_0 c}{k_{MC} + c} m \]
    \[ r_h = \frac{r_j}{Y} \]
  - Methanogen decay
    \[ r_k = k_2 m \]
**Bio-Chemical Model**

- McDougall's formulation:
  - Hydrolysis and acidogenesis
    \[ r_g = b\theta_e \phi P \]
  - Acetogenesis and methanogenesis
    \[ r_j = \frac{k_0c}{k_{MC} + c}m \]
    \[ r_h = \frac{r_j}{\gamma} \]
  - Methanogen decay
    \[ r_k = k_2m \]
**Bio-Chemical Model**

- Governing balance equations taking into account transport phenomena:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Balance equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Matter (<strong>Org</strong>)</td>
<td>$-\theta Z r_g = \frac{\partial \text{Org}}{\partial t}$</td>
</tr>
<tr>
<td>VFA (<strong>c</strong>)</td>
<td>$\text{div}(u. c) - \text{div}(D_h \nabla c) + [r_g - r_h] = \frac{\partial c}{\partial t}$</td>
</tr>
<tr>
<td>MB (<strong>m</strong>)</td>
<td>$\text{div}(u. m) - \text{div}(D_h \nabla m) + [r_j - r_k] = \frac{\partial m}{\partial t}$</td>
</tr>
</tbody>
</table>
Thermal model

- The degradation of the organic matter is an *exothermal reaction*.
- Classical heat storage and diffusion model:
  \[
  \dot{S}_T + \text{div}(V_T) - Q = 0 \\
  V_T = -\Gamma \nabla T + c_{p,w} \rho_w f_w (T - T_0)
  \]
- Heat generation term based on the variation of the organic content:
  \[
  Q = \frac{\Delta \text{Org}(t)}{\Delta t} Q_m
  \]
The degradation of the organic matter is going to modify the mechanical properties of the MSW.

Chemo-Hydro-Mechanical model introduced by Liu & al

\[ \dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^e + \dot{\varepsilon}_{ij}^p \]

- Classical elastic stress-strain relationship
- The plastic strain rate is defined within the boundaries of the yield criterion:
  \[ f(\sigma_{ij}, \kappa) \leq 0 \]
Mechanical model

Three plastic yielding mechanisms are implemented into the CHM:

- pore collapse
- frictional-cohesive failure
- tensile failure
Mechanical model

- The degradation of the organic matter induces hardening/softening:

  - “Concentration” parameter:

    \[ \alpha = 1 - \frac{\text{Org}}{\text{Org}_0} \]

  - Effect of the concentration on the yield surface:

    \[
    p_0(\alpha) = p_0^* S(\alpha) \\
    p_s = p_s^* + k_{OC} \alpha
    \]
SUMMARY OF THE PRESENTATION

- Introduction to the waste management issue
- THBCM multi-physics model
  - Hydraulic model
  - Bio-chemo model
  - Thermal model
  - Mechanical model
- Test simulation and results
- Conclusion
Geometry and initial/boundaries conditions

- **Goal**: Assess the performance and validity of the model
- **Very simple 1D geometry**

\[
\begin{align*}
\text{Org}_0 &= 300 \text{ kg/m}^3 \\
T_0 &= 20 \ ^\circ\text{C} \\
\theta &= 30\% \\
c_0 &= 300 \text{ g/m}^3_{\text{aquous}} \\
m_0 &= 2.5 \text{ g/m}^3_{\text{aquous}}
\end{align*}
\]

Water is collected
\[ \Rightarrow p_w = 90 \text{ kPa} \]
Hydraulic results

\[ Q = 2.5 \times 10^{-8} m^3/s \]

Injected water flux

\[ Q = 2.5 \times 10^{-6} m^3/s \]

Bio-chemical results

$Q = 2.5 \times 10^{-8} m^3/s$

Bio-chemical results

$Q = 2.5 \times 10^{-8} m^3/s$  Injected water flux  $Q = 2.5 \times 10^{-6} m^3/s$

Bio-chemical results

Mechanical results

\[ Q = 2.5 \times 10^{-8} m^3/s \]

Injected water flux

\[ Q = 2.5 \times 10^{-6} m^3/s \]
Conclusion

- Results linked to the hydraulic equilibrium reached
- Can work on any given geometry
- Thermal model not fully linked
- Effective to assess settlements
- Effective tool for pollution potential evaluation
Questions