University of Liège – Department ArGEnCo

2014 – 2015

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

5^{th} *of November* 2014
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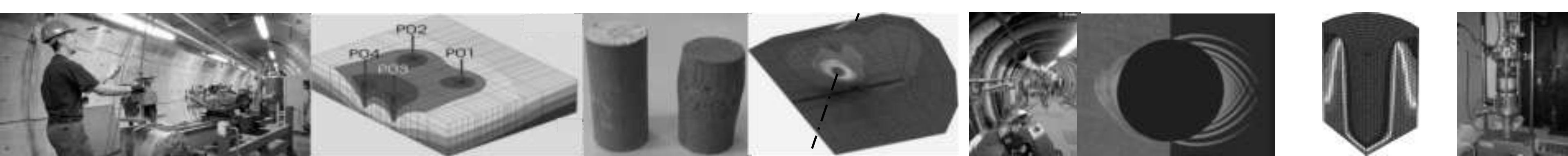
<u>Promoteur</u> : Frédéric Collin



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$\nearrow \begin{cases} \text{Demographic explosion} \\ \text{Over} - \text{Consumption} \end{cases}$

WASTE MANAGEMENT ISSUE

- Waste production ↗
- It has to be taken care of :

WASTE

Prevention	Recycling	Composting	Incineration	Landfills
				

Best option → Worst option

Sanitary landfills management

- One of the key point of the waste management issue
- Objective : optimal post closure management

→ Evaluation of long term settlements

→ Sustainable development

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HYDRAULIC MODEL

- MSW behave like an unsaturated soil :

$$\frac{\partial(\rho_w n S_{r,w})}{\partial t} + div\left(\rho_w \underline{f_w}\right) = Q$$

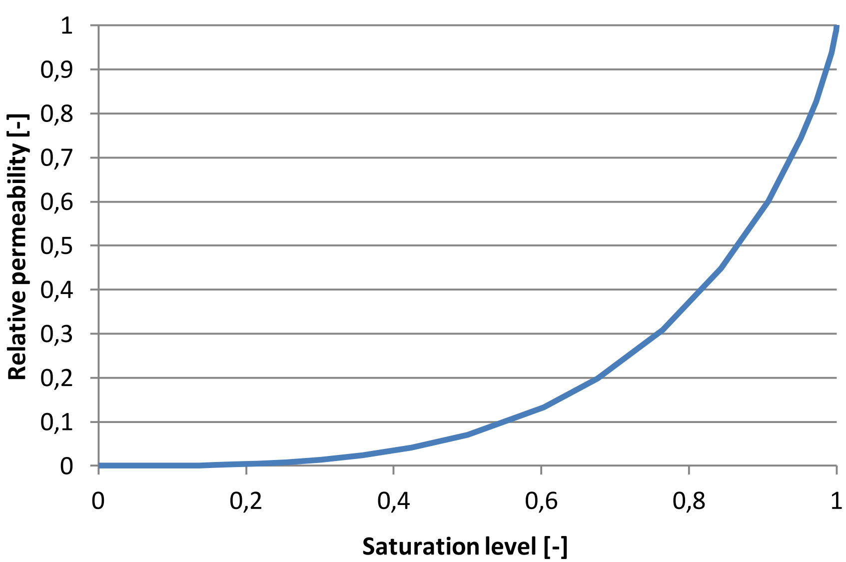
$\underline{f_w}$ is the Darcy's flow given by the following equation:

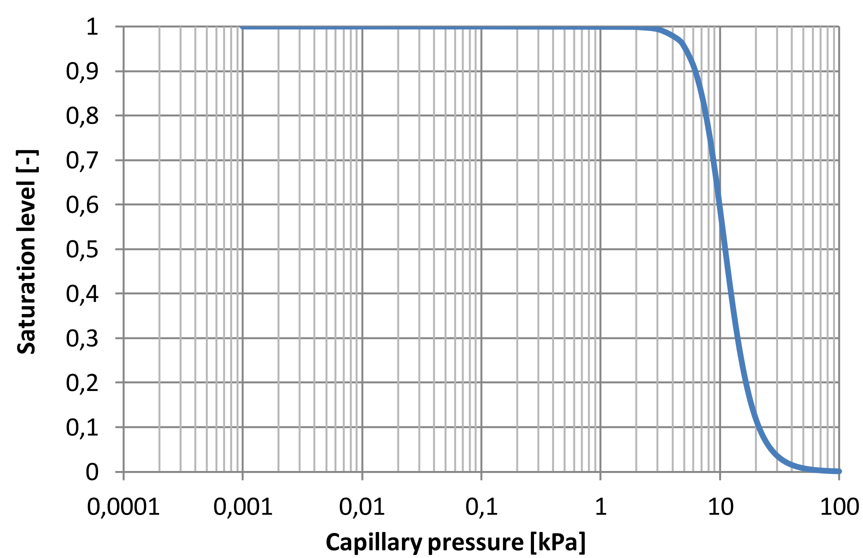
$$\underline{f_w} = -\frac{k_w(S_{r,w})}{\mu_w}(grad(p_w) + \rho_w . g . grad(y))$$

HYDRAULIC MODEL

Relative permeability and water retention curves (van Genuchten):

Relative permeability	Water retention
$k_{rel} = \sqrt{S_{r,w}}\left[1-\left(1-S_{r,w}{}^{\frac{1}{mvG}}\right)^{m_{vG}}\right]^2$	$S_{r,w} = S_{res} + (S_{sat} - S_{res})\left[\left(1+\frac{p_c}{\alpha}\right)^{n_{vG}}\right]^{-m_{vG}}$

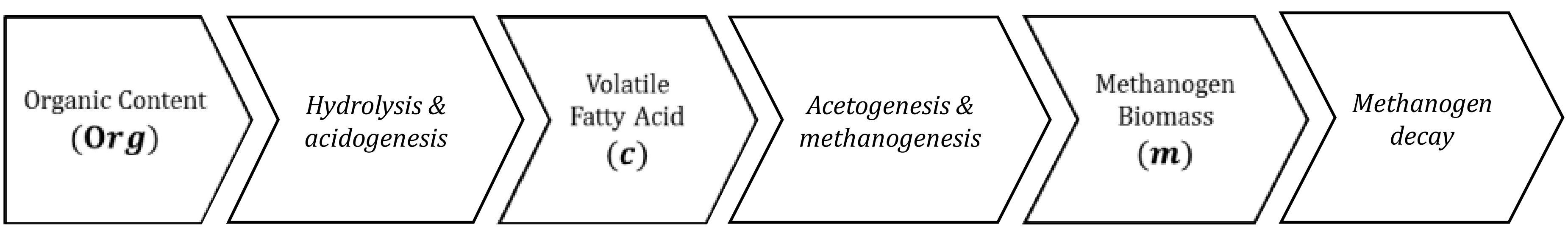




BIO-CHEMICAL MODEL

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

It is assumed it can be simplified :



BIO-CHEMICAL MODEL

- McDougall's formulation:
  - Hydrolysis and acidogenesis

$$r_g = b\theta_e \phi P$$

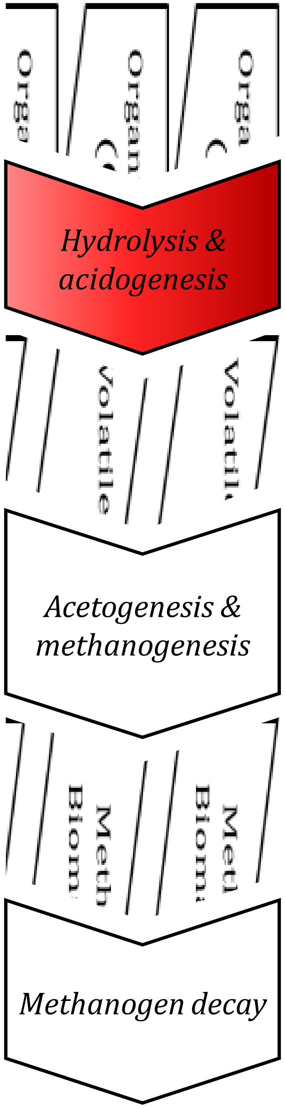
  - Acetogenesis and methanogenesis

$$r_j = \frac{k_0 c}{k_{MC} + c} m$$

$$r_h = \frac{r_j}{Y}$$

  - Methanogen decay

$$r_k = k_2 m$$



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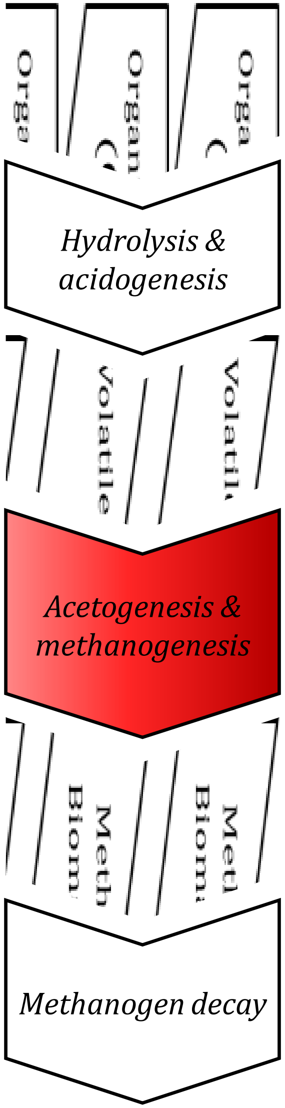

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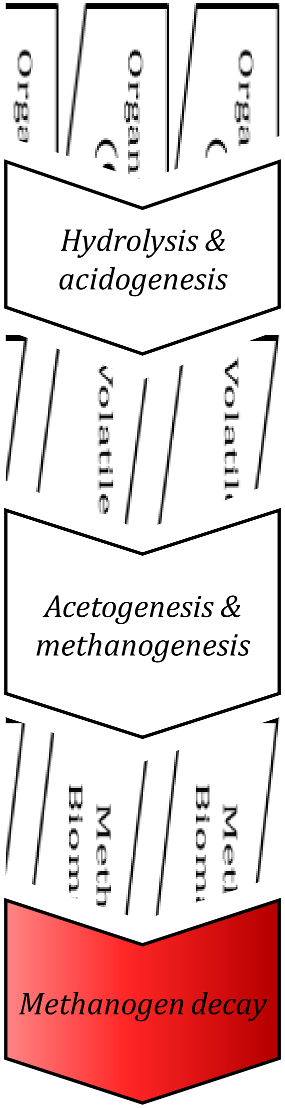


BIO-CHEMICAL MODEL

- Governing balance equations taking into account transport phenomena :

Variable	Balance equation
Organic Matter ($\boldsymbol{Org}$):	$-\theta Z r_g = \frac{\partial Org}{\partial t}$
VFA ($\boldsymbol{c}$):	$div(u.c\ ) - div(D_h \nabla c) + [r_g - r_h] = \frac{\partial c}{\partial t}$
MB ($\boldsymbol{m}$):	$div(u.m\ ) - div(D_h \nabla m) + [r_j - r_k] = \frac{\partial m}{\partial t}$

Thermal model

- The degradation of the organic matter is an exothermal reaction

- Classical heat storage and diffusion model :

$$\dot{S}_T + div(V_T) - Q = 0$$

$$V_T = -\Gamma \nabla T + c_{p,w} \rho_w \underline{f_w} (T - T_0)$$

- Heat generation term based on the variation of the organic content :

$$Q = \frac{\Delta Org(t)}{\rho_d \Delta t} \rho_d Q_m$$

Mechanical model

- The degradation of the organic matter is going to modify the mechanical properties of the MSW

- Chemo-Hydro-Mechanical model introduced by Liu *& al*

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

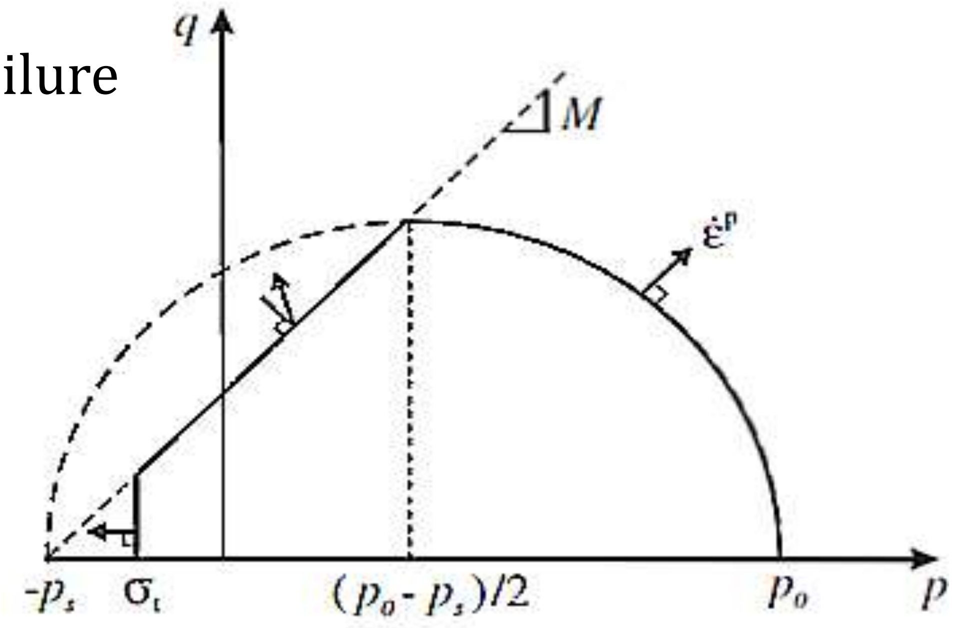
  - Classical elastic stress-strain relationship

  - 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 :

$$OC = 1 - \frac{Org}{Org_0}$$

  - Effect of the concentration on the yield surface:

$$p_0(OC) = p_0^* S(OC)$$

$$p_s = p_s^* + k_{OC} OC$$

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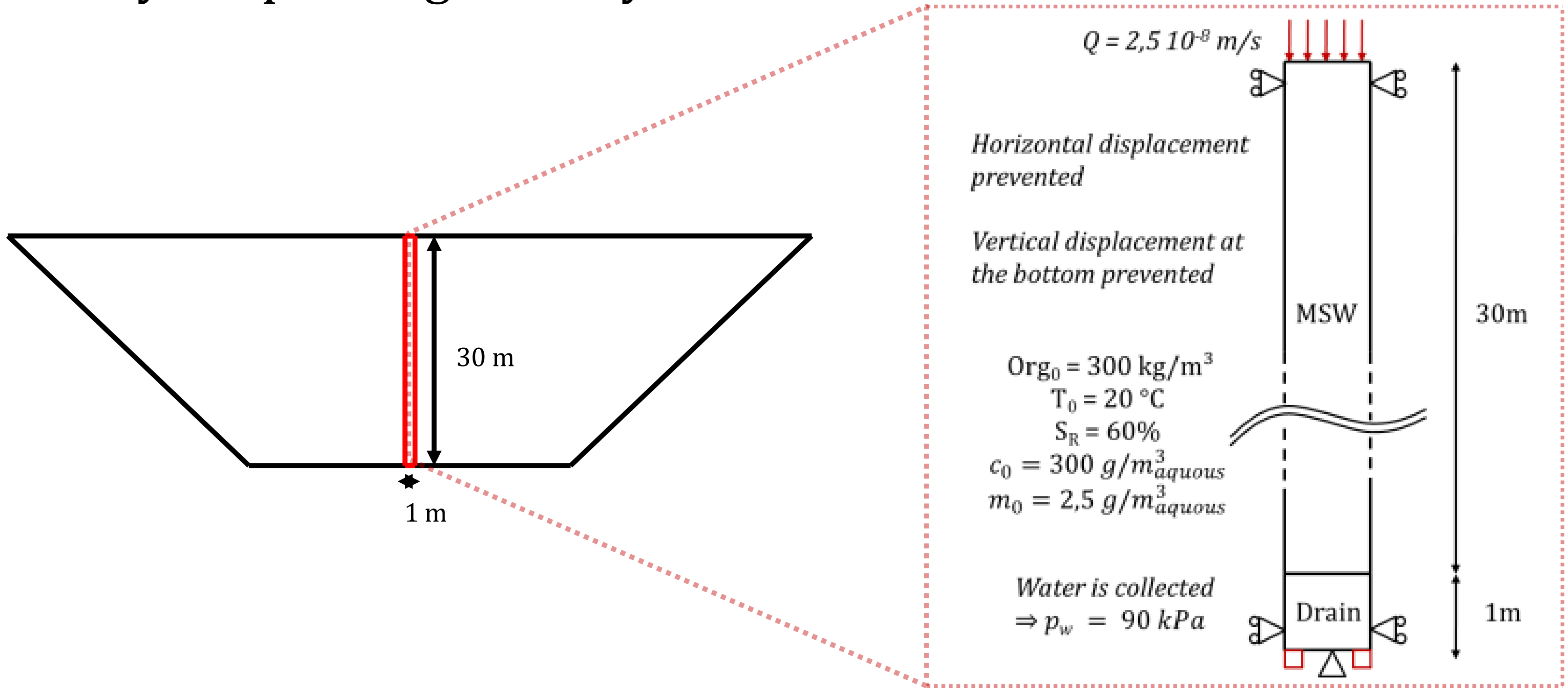
Geometry and initial/boundaries conditions

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

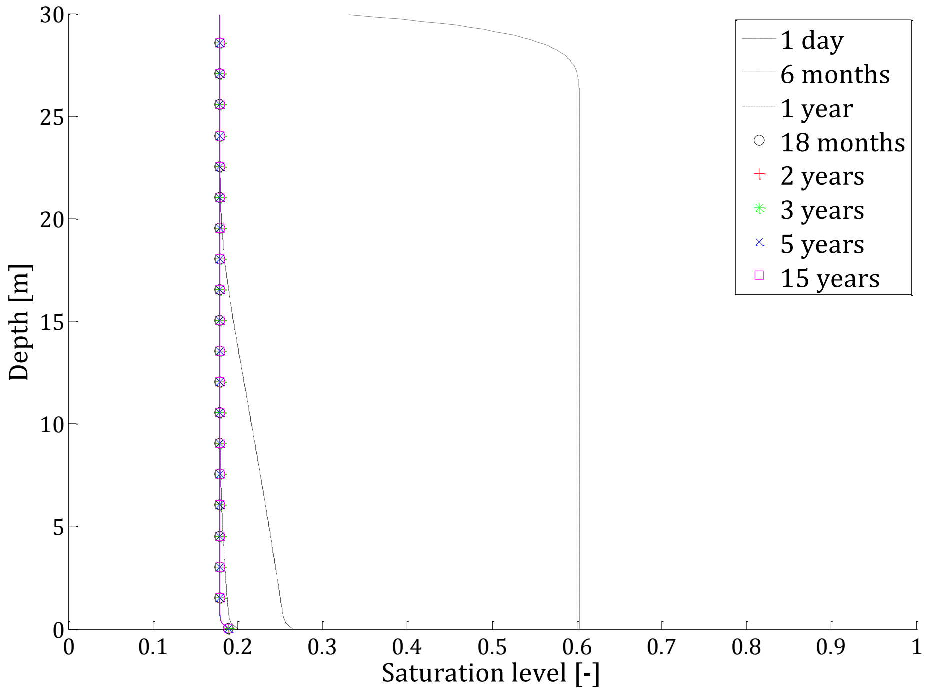


Hydraulic results

Authors	$S_{rés}$	α $[kPa]$	n
(Feng & Zhang, 2014)	0	10	4

Authors	Parameters	Values	Units
(MANASSERO, VAN IMPE, & BOUAZZA, 1996)	Permeability	$[10^{-8} ; 10^{-4}] \Longrightarrow 10^{-5}$	[m/s]
(Olivier & Gourc, 2007) (Staub, Galietti, Oxarango, Khire, & Gourc, 2009)	Porosity	$[0.48 ; 0.51] \Longrightarrow 0.5$	[-]

Evolution of the saturation level

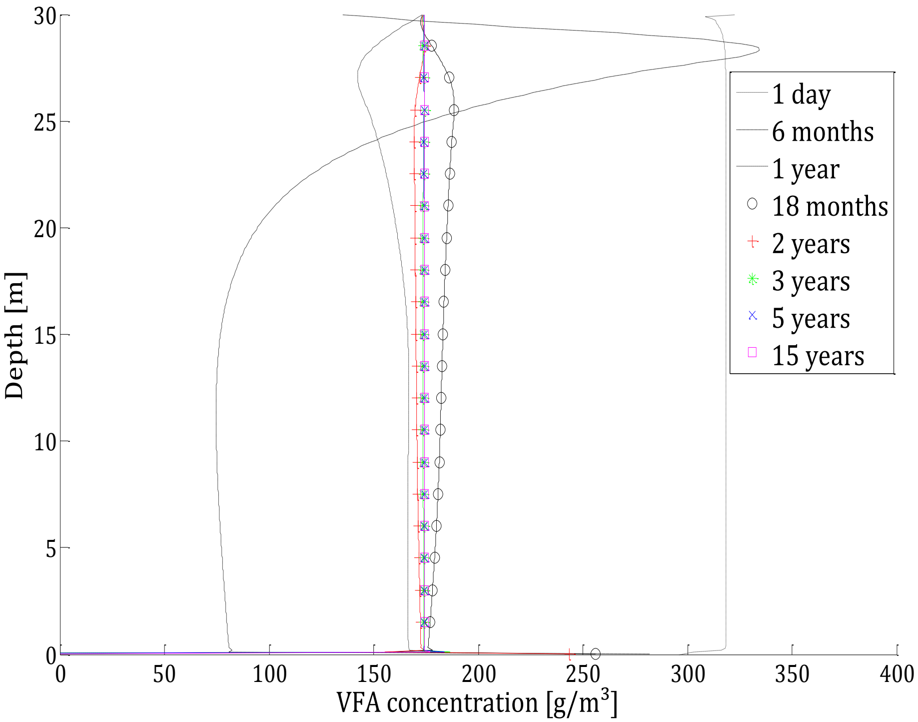


Bio-chemical results

Authors	Parameters	Values	Units
(Domenico & Schwartz, 1998)	Lateral dispersivity	0.002	m
(Domenico & Schwartz, 1998)	Longitudinal dispersivity	0.02	m
(Cooke & Rowe, 2008)	Molecular diffusion	$1.736\ 10^{-9}$	m^2/s

Authors	Parameters	Values	Units
(McDougall J. , 2007)	b	0.029	$[g/m^3 d'eau * s^{-1}]$
	Org_0	300000	$[g/m^3]$
	n	0.36	$[-]$
	k_{AGV}	0.0002	$[m^3\ d'eau/g]$
	Y	0.08	$[-]$
	k_0	$5.7 * 10^{-6}$	$5.7 * 10^{-6}$
		4200	4200
		$2.3 * 10^\wedge - 7$	$2.3 * 10^\wedge -$

Evolution of the VFA concentration



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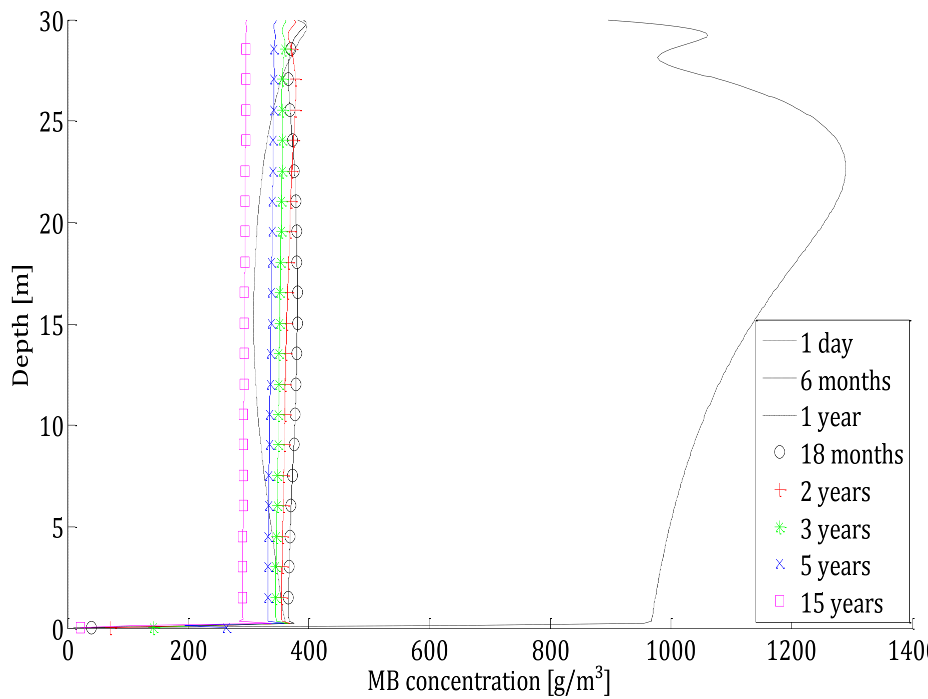
		$5.7 * 10^{-6}$	$5.7 * 10^{-6}$
		4200	4200
		2.3 * 10^ − 7	2.3 * 10^ −

Evolution of the MB concentration



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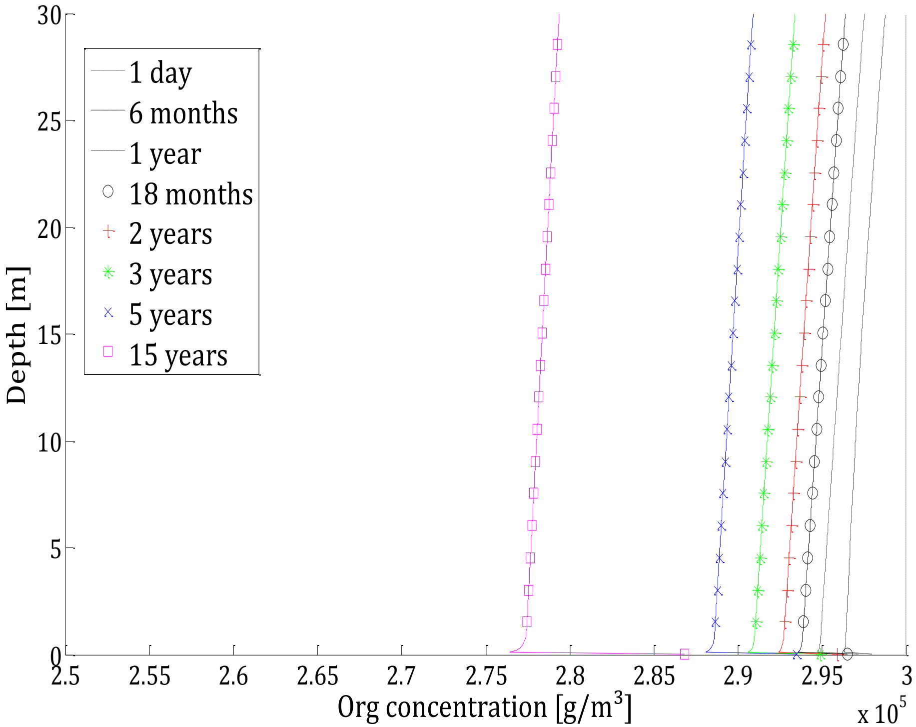
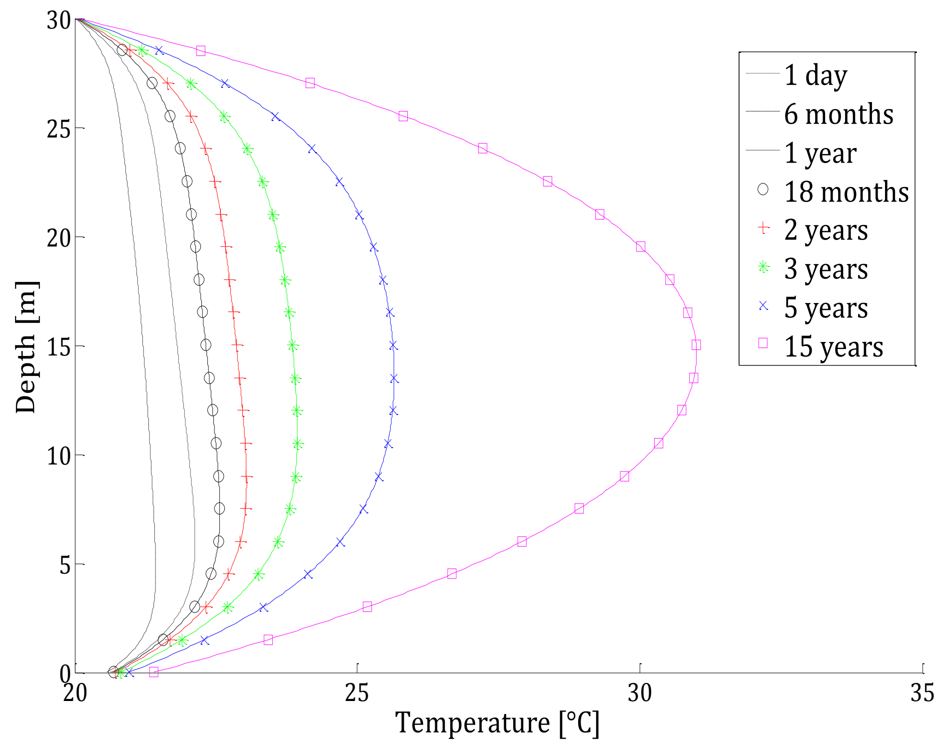
		$2.3 * 10^\wedge - 7$	$2.3 * 10^\wedge -$

Evolution of the organic content



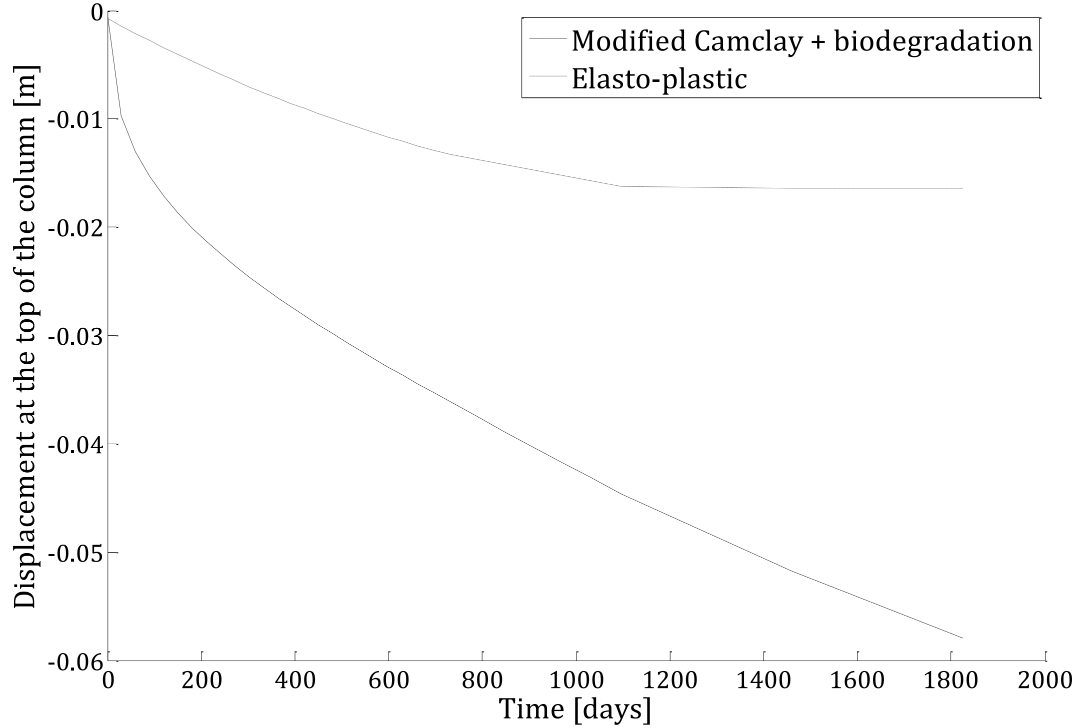
Thermal results

Authors	Parameters	Values	Units
(Yoshida, Tanaka, & HozumiI, 1999)	c_d	1939	$[\frac{J}{kg * K}]$
	ρ_d	1000	$[kg/m^3]$
	ρ_d	4185	$[kg/m^3]$
	ρ_w	1000	$[kg/m^3]$
	c_w	1004	$[\frac{J}{kg * K}]$
	ρ_a		$[kg/m^3]$
(Boukpeti, 2004)	Q_m	632	$[kJ/kg]$
(Olivier & Gourc, 2007) (Staub, Galietti, Oxarango, Khire, & Gourc, 2009)	n		$[-]$



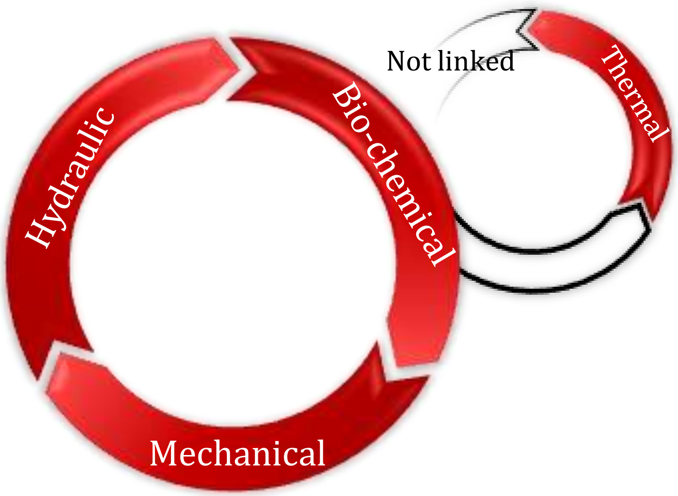
Mechanical results

Parameters	Values	Units
λ	0.0648	$[-]$
κ	0.00792	$[-]$
a	3.45	$[-]$
κ	0.00792	$[-]$
ρ	1000	$[kg/m^3]$



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