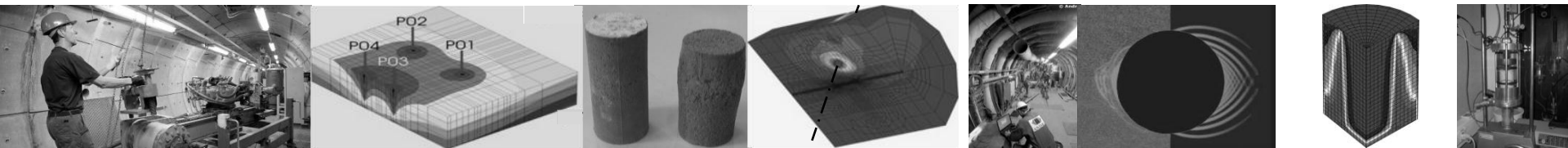


THBCM Multi-Physics Model : development and numerical application

Promoteur : Frédéric Collin

5th of November 2014

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

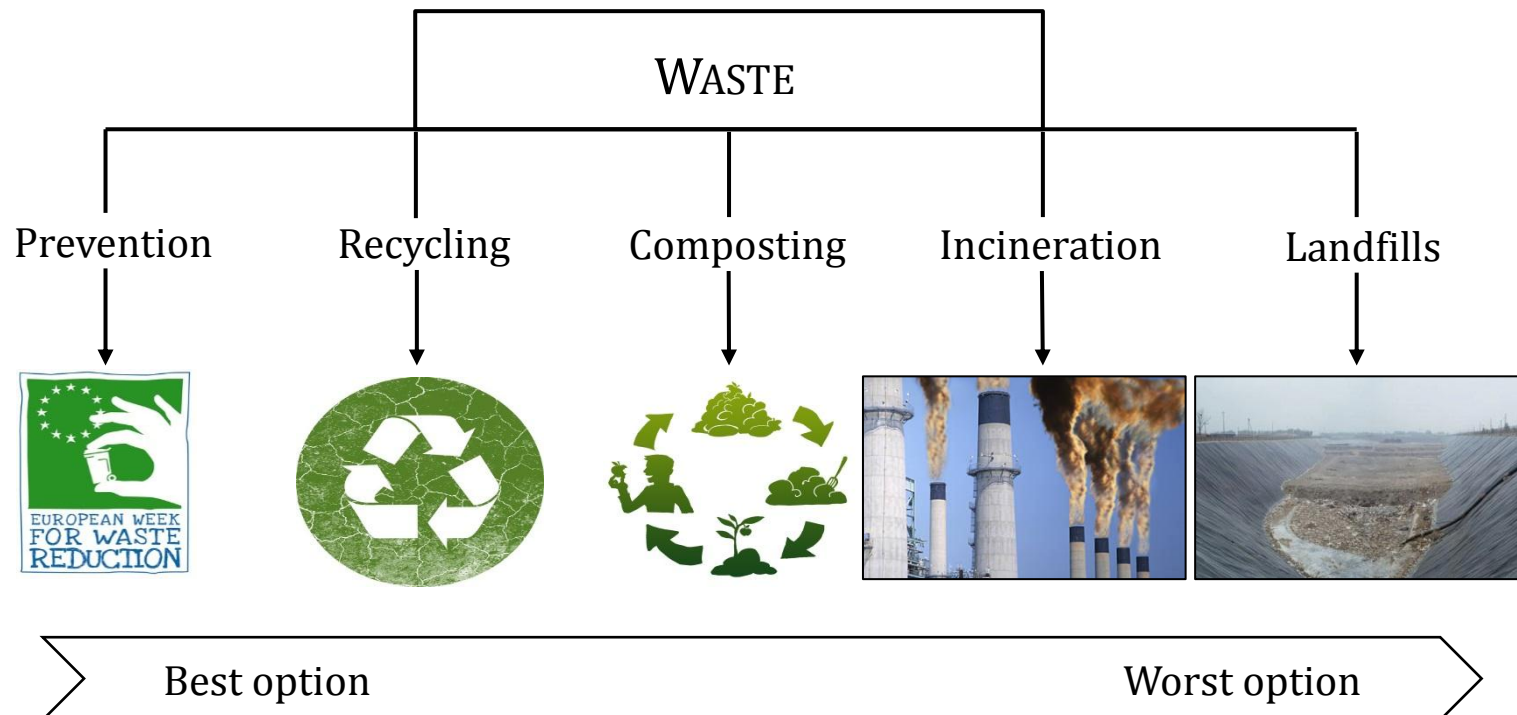
WASTE MANAGEMENT ISSUE

- Waste production \nearrow $\left\{ \begin{array}{l} \text{Demographic explosion} \\ \text{Over - Consumption} \end{array} \right.$



WASTE MANAGEMENT ISSUE

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



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 :

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

f_w is the Darcy's flow given by the following equation:

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

HYDRAULIC MODEL

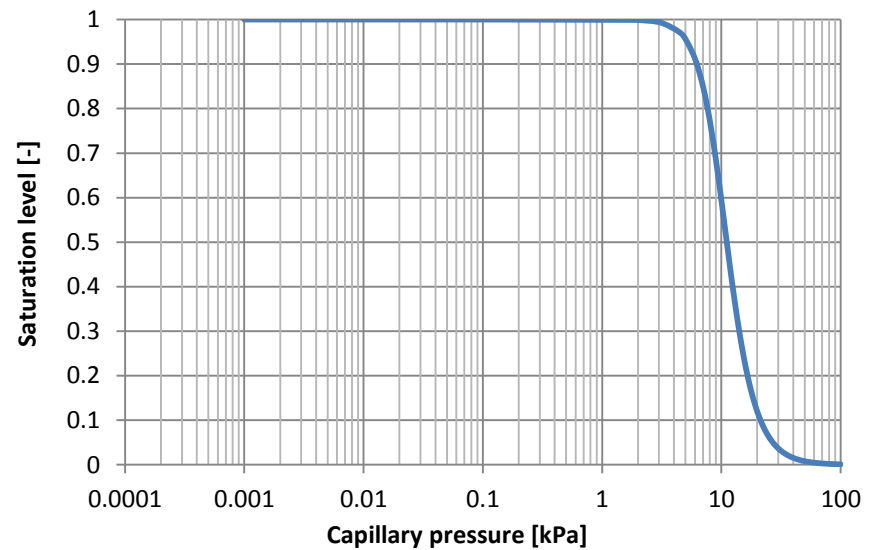
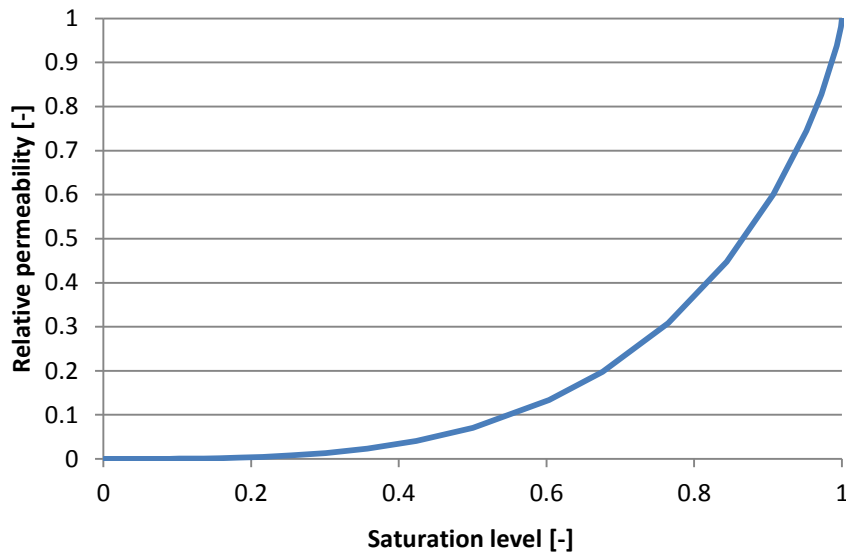
Relative permeability and water retention curves (van Genuchten):

Relative permeability

$$k_{rel} = \sqrt{S_{r,w}} \left[1 - \left(1 - S_{r,w}^{\frac{1}{m_{vG}}} \right)^{m_{vG}} \right]^2$$

Water retention

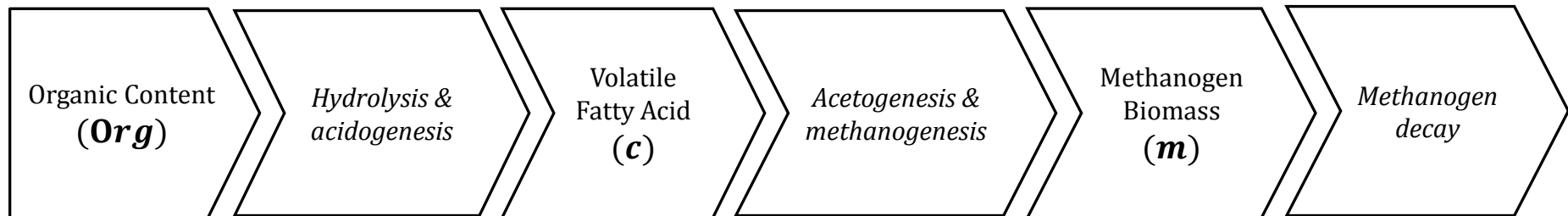
$$S_{r,w} = S_{res} + (S_{sat} - S_{res}) \left[\left(1 + \frac{p_c}{\alpha} \right)^{n_{vG}} \right]^{-m_{vG}}$$



BIO-CHEMICAL MODEL

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

It is assumed it can be simplified :



BIO-CHEMICAL MODEL

- McDougall's formulation:

- Hydrolysis and acidogenesis

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

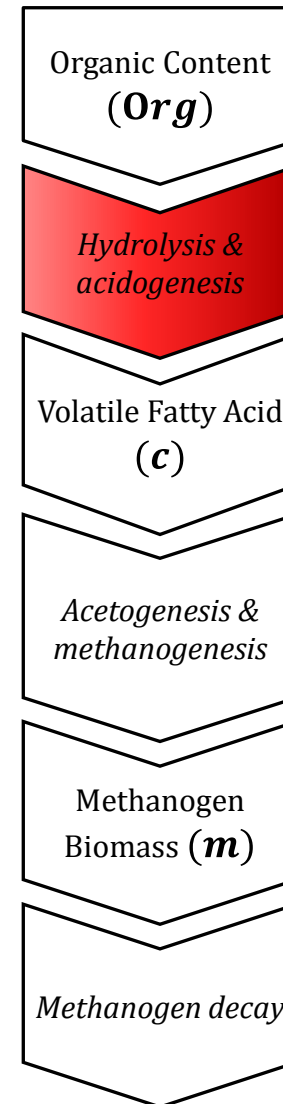
- Acetogenesis and methanogenesis

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

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

- Methanogen decay

$$r_k = k_2 m$$



BIO-CHEMICAL MODEL

- McDougall's formulation:

- Hydrolysis and acidogenesis

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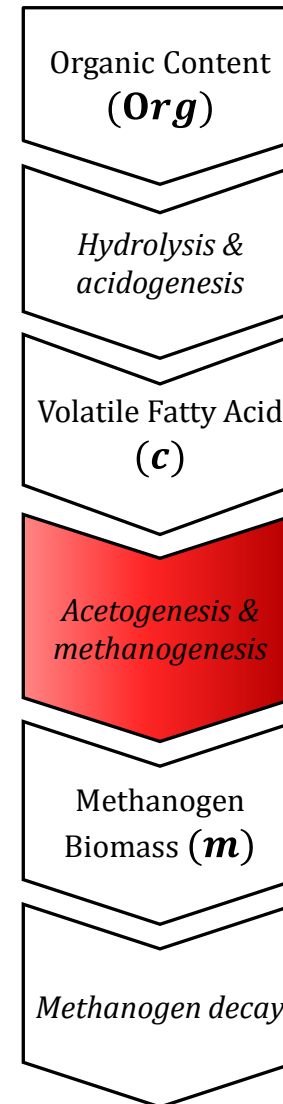
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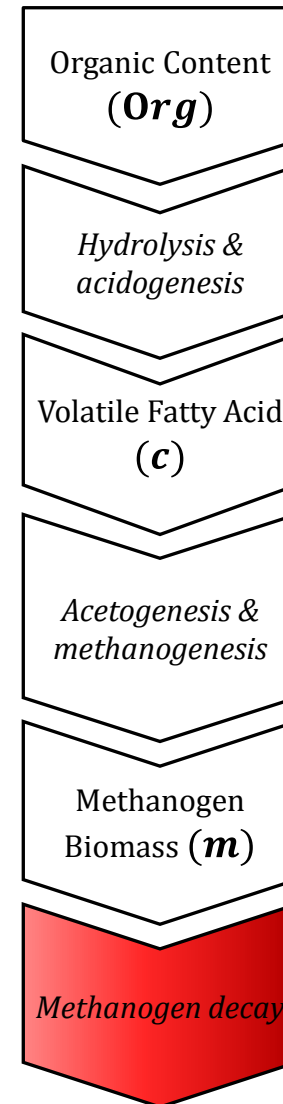
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BIO-CHEMICAL MODEL

- Governing balance equations taking into account transport phenomena :

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

Thermal model

- The degradation of the organic matter is an exothermal reaction
- Classical heat storage and diffusion model :

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

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

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

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

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*

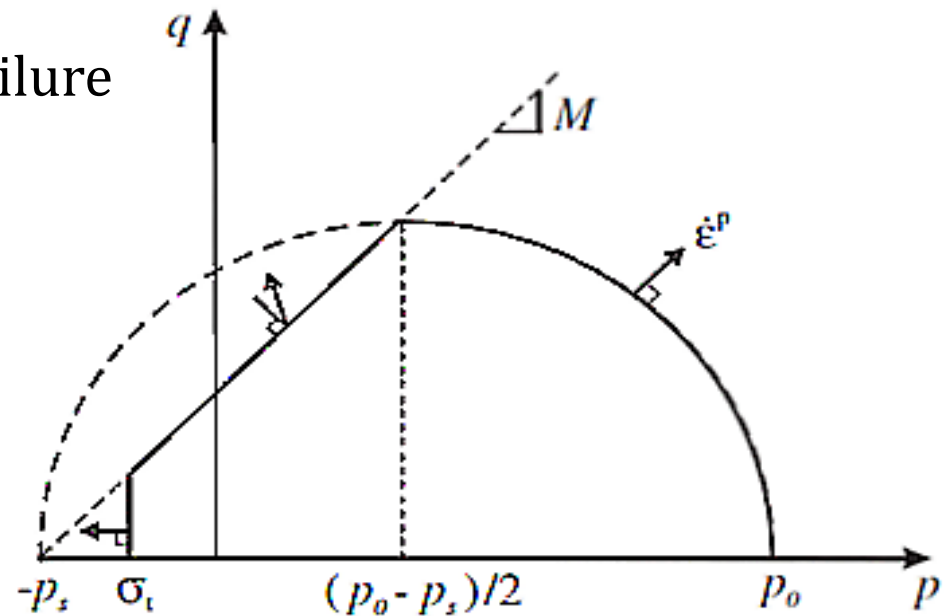
$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^e + \dot{\varepsilon}_{ij}^p$$

- 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:

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

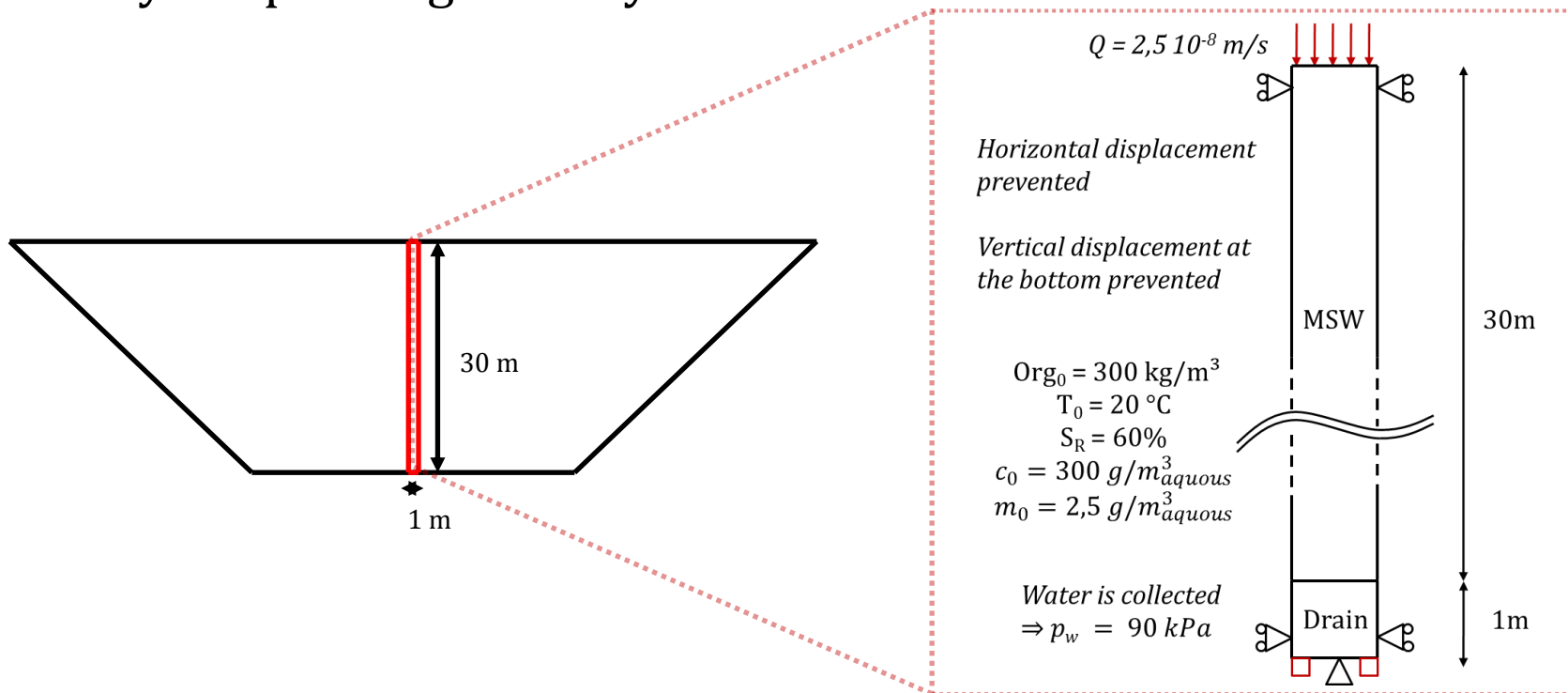
$$p_s = p_s^* + k_{OC} OC$$

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Geometry and initial/boundaries conditions

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

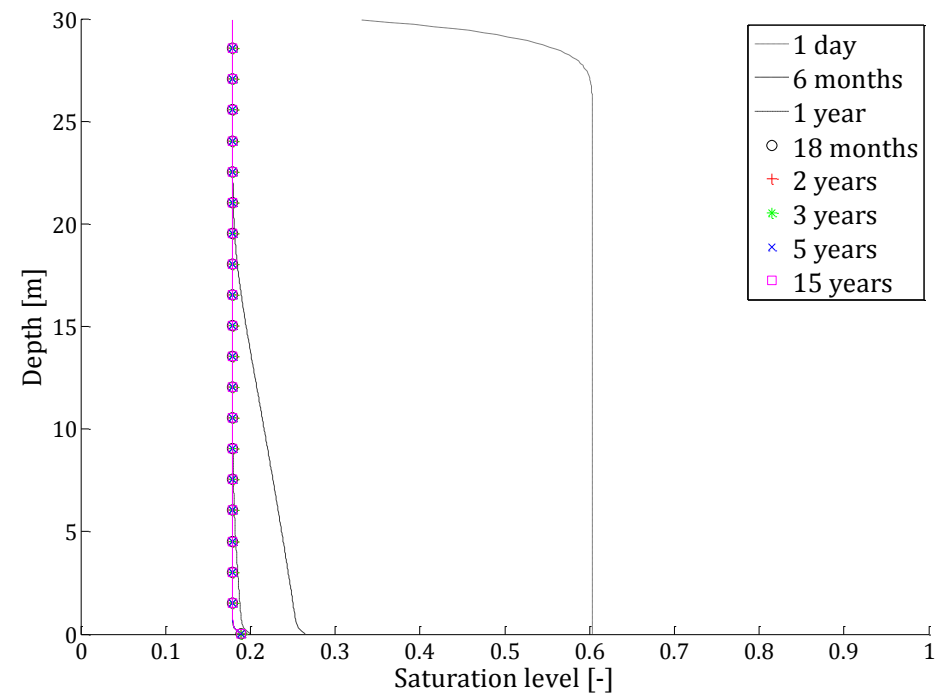


Hydraulic results

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

AUTHORS	PARAMETERS	VALUES	UNITS
(MANASSERO, VAN IMPE, & BOUAZZA, 1996)	Permeability	$[10^{-8}; 10^{-4}] \Rightarrow 10^{-5}$	[m/s]
(Olivier & Gourc, 2007) (Staub, Galietti, Oxarango, Khire, & Gourc, 2009)	Porosity	$[0.48; 0.51] \Rightarrow 0.5$	[-]

Evolution of the saturation level

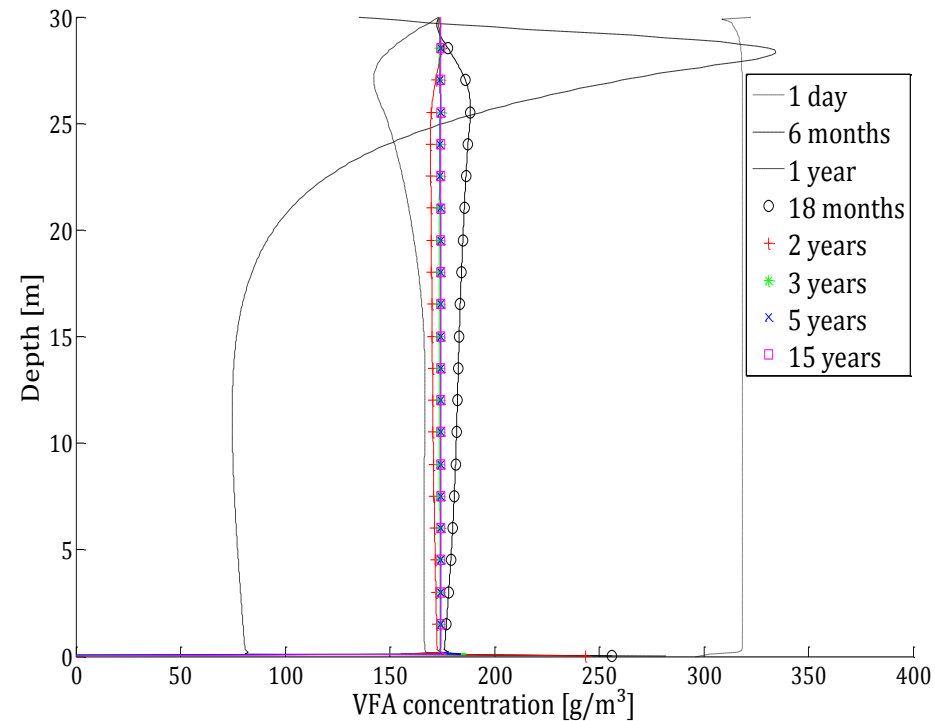


Bio-chemical results

AUTHORS	PARAMETERS	VALUES	UNITS
(Domenico & Schwartz, 1998)	Lateral dispersivity	0.002	<i>m</i>
(Domenico & Schwartz, 1998)	Longitudinal dispersivity	0.02	<i>m</i>
(Cooke & Rowe, 2008)	Molecular diffusion	$1.736 \cdot 10^{-9}$	m^2/s

AUTHORS	PARAMETERS	VALUES	UNITS
	<i>b</i>	0.029	$[g/m^3 d' eau * s^{-1}]$
	<i>Org₀</i>	300000	$[g/m^3]$
	<i>n</i>	0.36	[-]
(McDougall J., 2007)	<i>k_{AGV}</i>	0.0002	$[m^3 d' eau/g]$
	<i>Y</i>	0.08	[-]
	<i>k₀</i>	$5.7 \cdot 10^{-6}$	$[s^{-1}]$
	<i>k_{MC}</i>	4200	$[g/m^3 d' eau]$
	<i>k₂</i>	$2.3 \cdot 10^{-7}$	$[s^{-1}]$

Evolution of the VFA concentration

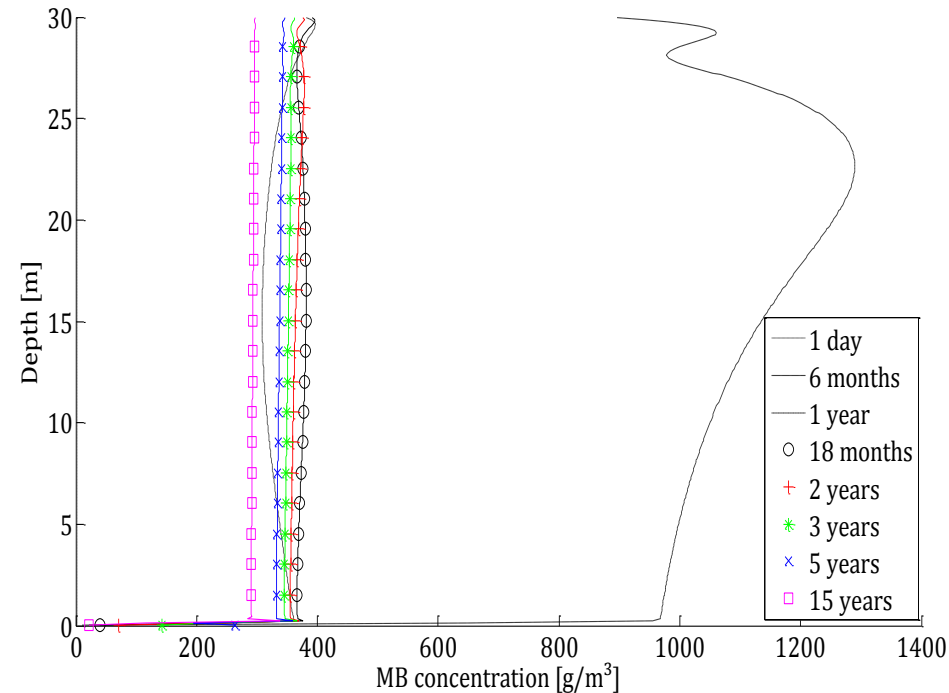


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	k_{AGV}	0.0002	$[m^3 d' eau/g]$
	<i>Y</i>	0.08	[-]
	k_0	$5.7 \cdot 10^{-6}$	$[s^{-1}]$
	k_{MC}	4200	$[g/m^3 d' eau]$
	k_2	$2.3 \cdot 10^{-7}$	$[s^{-1}]$

Evolution of the MB concentration

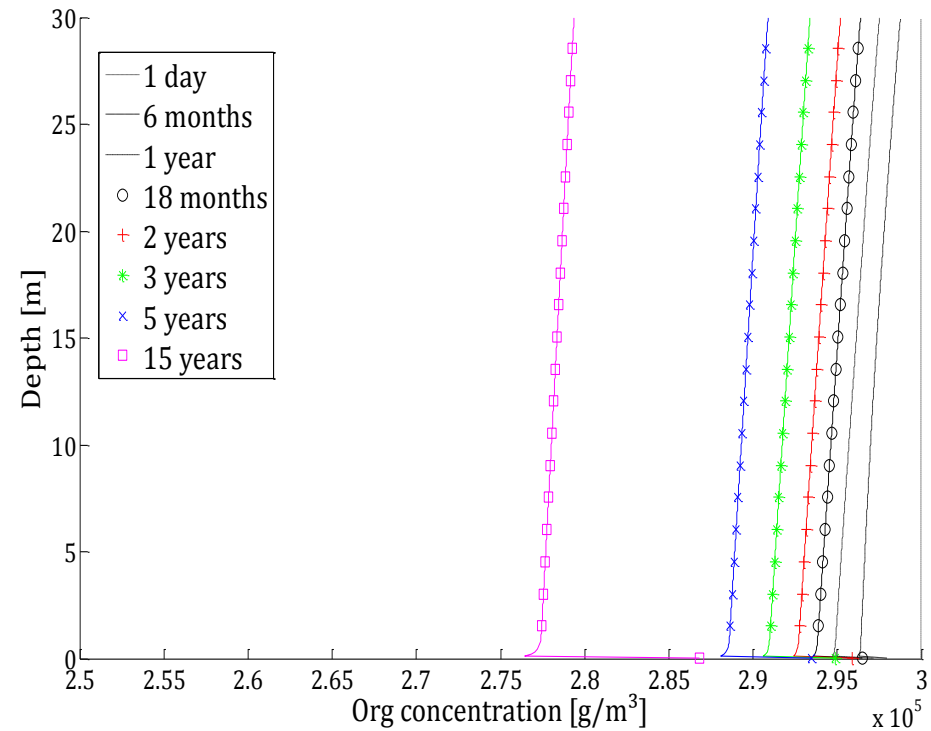


Bio-chemical results

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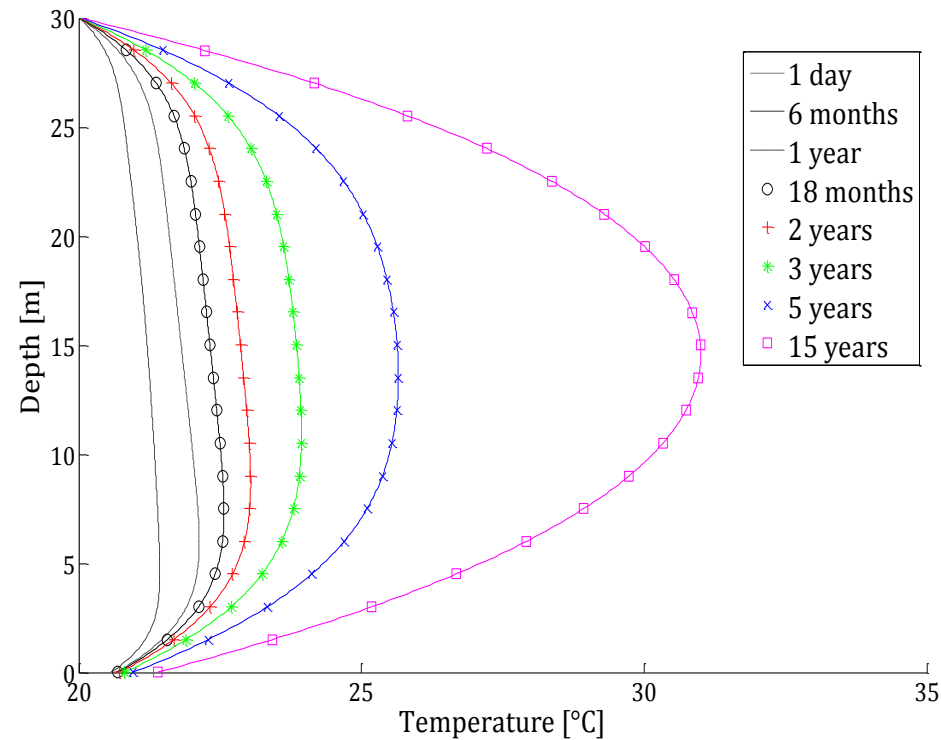
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	<i>Y</i>	0.08	[-]
	<i>k₀</i>	$5.7 \cdot 10^{-6}$	$[s^{-1}]$
	<i>k_{MC}</i>	4200	$[g/m^3 d' eau]$
	<i>k₂</i>	$2.3 \cdot 10^{\wedge} - 7$	$[s^{-1}]$

Evolution of the organic content



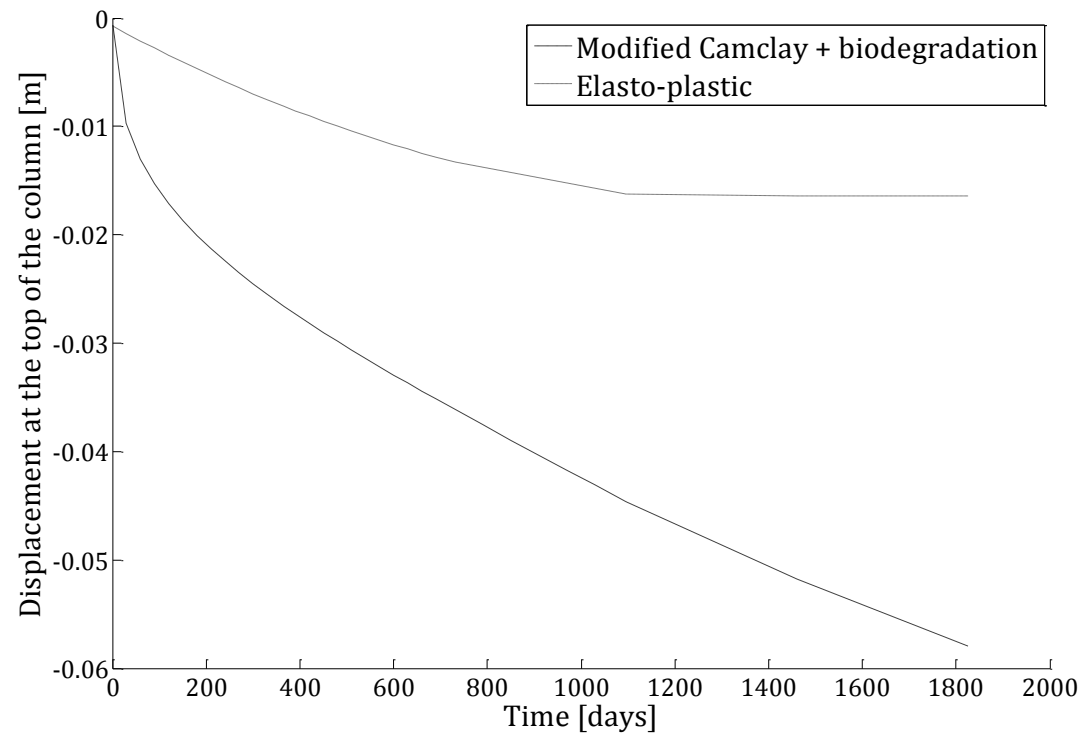
Thermal results

AUTHORS	PARAMETERS	VALUES	UNITS
(Yoshida, Tanaka, & Hozumil, 1999)	c_d	1939	$\frac{J}{kg * K}$
	ρ_d	1000	$[kg/m^3]$
	c_w	4185	$\frac{J}{kg * K}$
	ρ_w	1000	$[kg/m^3]$
	c_a	1004	$\frac{J}{kg * K}$
(Boukpeti, 2004)	ρ_a	1.2	$[kg/m^3]$
(Olivier & Gourc, 2007) (Staub, Galietti, Oxarango, Khire, & Gourc, 2009)	Q_m	632	$[kJ/kg]$
	n	0.5	$[-]$



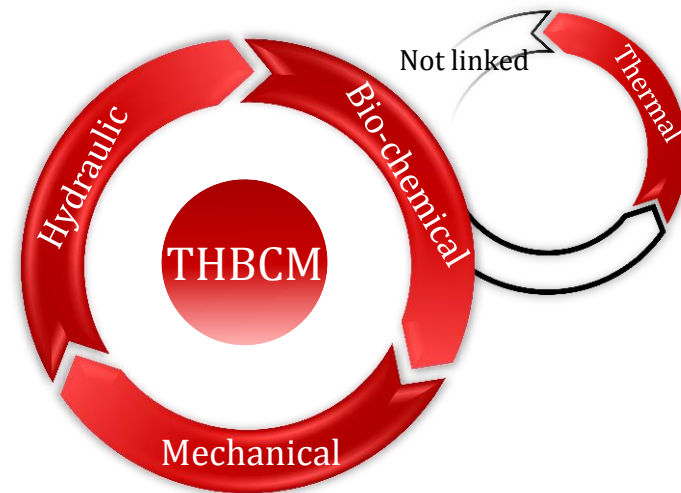
Mechanical results

PARAMETERS	VALUES	UNITS
λ	0.0648	[-]
κ	0.00792	[-]
a	3.45	[-]
$OCR = \frac{p_0}{p}$	1.01	[-]
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