34èmes Rencontres Universitaires de Génie Civil de l'AUGC

Boom clay drying behavior: experimental and numerical study

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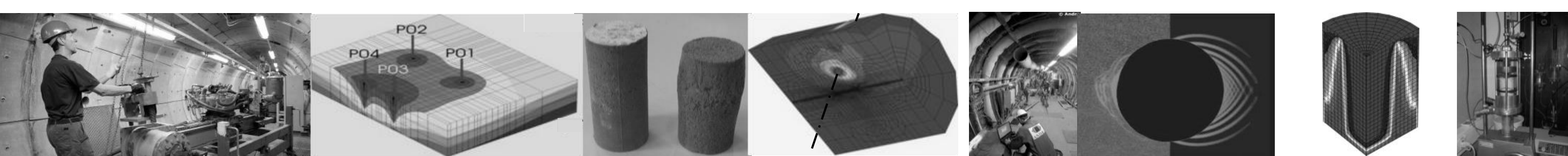
Thesis director : Frédéric Collin

Wednesday 25^{th} *of May*



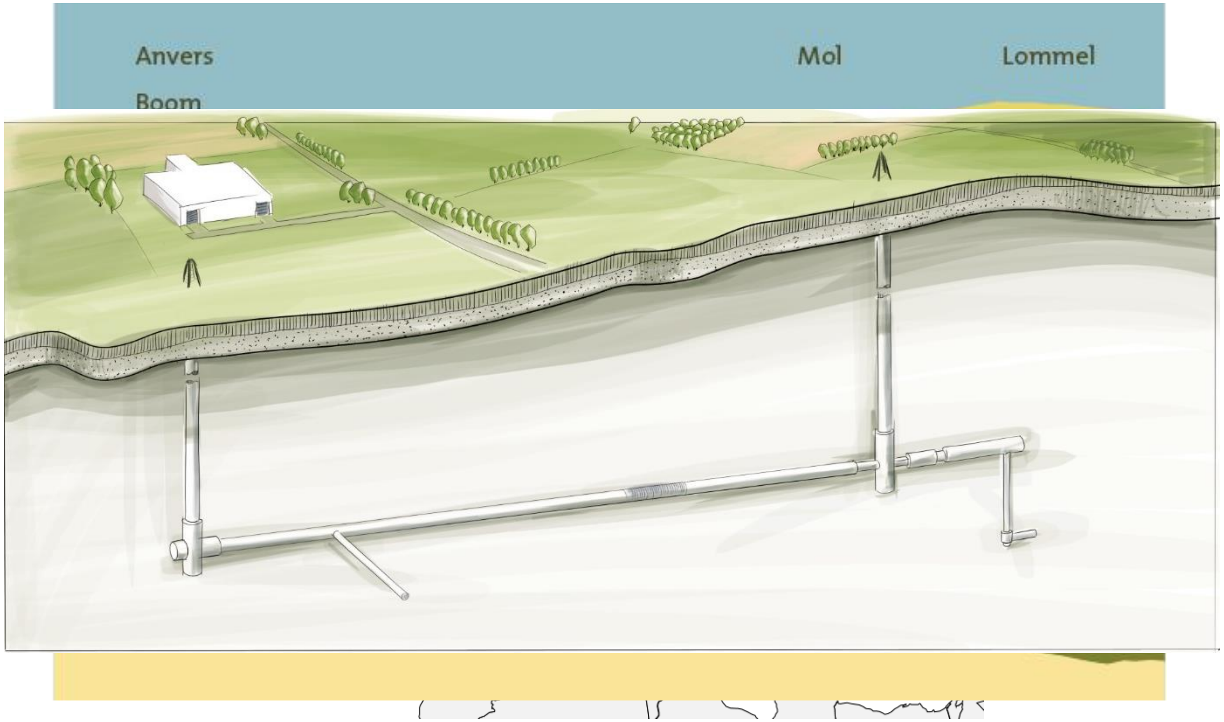
SUMMARY OF THE PRESENTATION

- Nuclear waste disposal
- Material and method
- Drying kinetics
- Shrinkage
- Conclusions

NUCLEAR WASTE DISPOSAL

- High activity long life **radioactive wastes** need to be **isolated** for a **long period of time** ⇒ **Deep geological disposal**
  - Stable and low permeability rock formation required

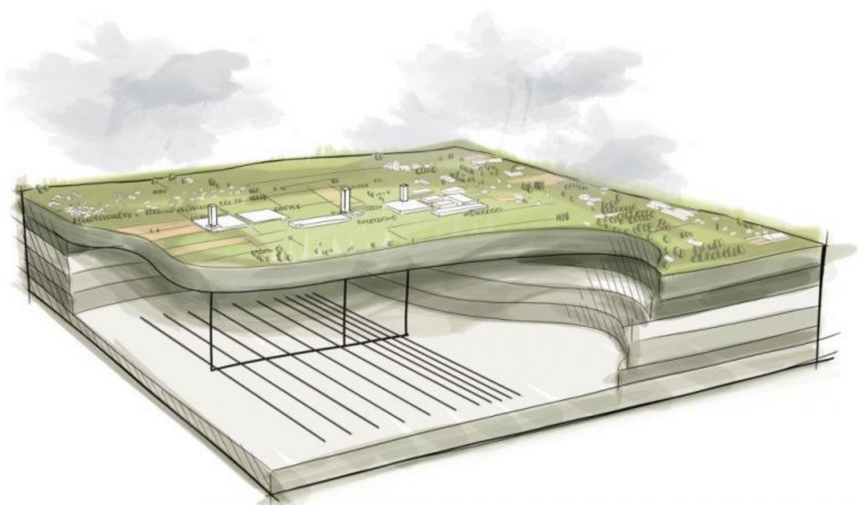
    ⇒ in **Belgium** the studied formation is **Boom Clay**

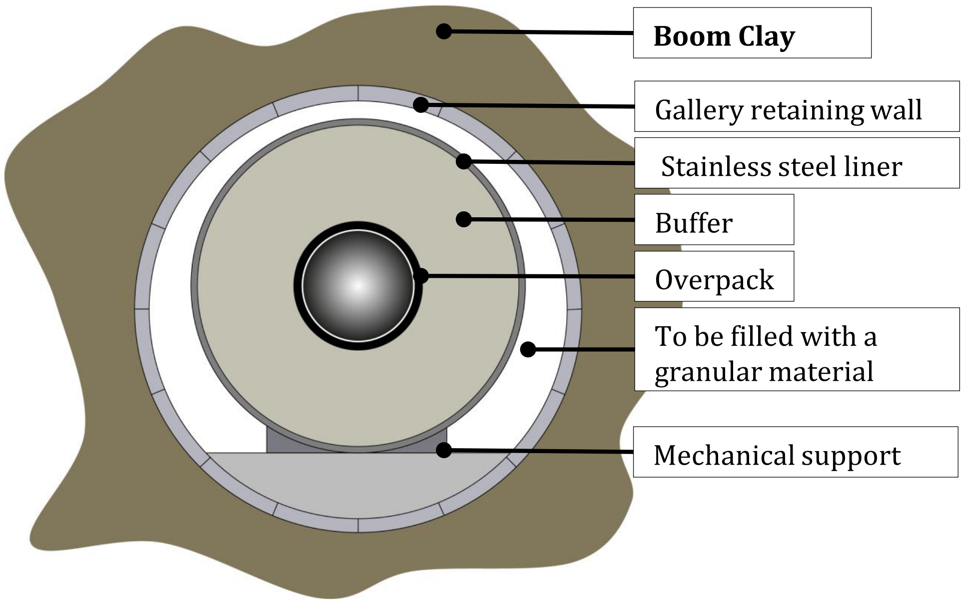


ONDRAF

NUCLEAR WASTE DISPOSAL

- Deep geological storage
  - Burial shaft and multi barrier principle:





Craye et al., 2009

SUMMARY OF THE PRESENTATION

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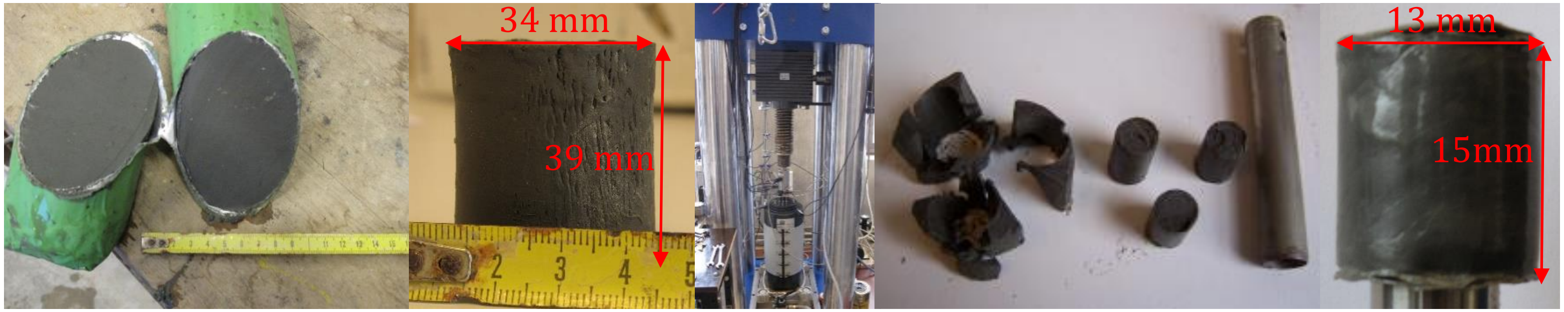
Material and method

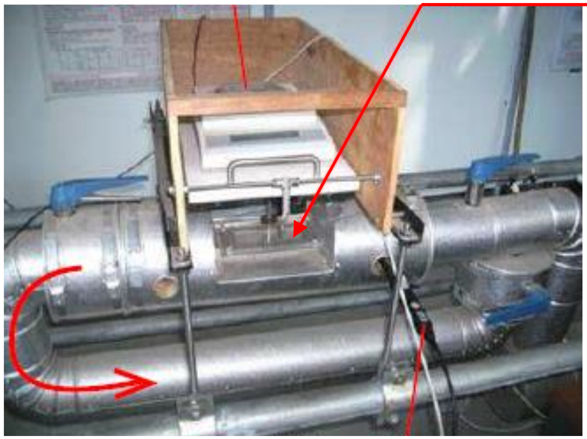
- Samples preparation

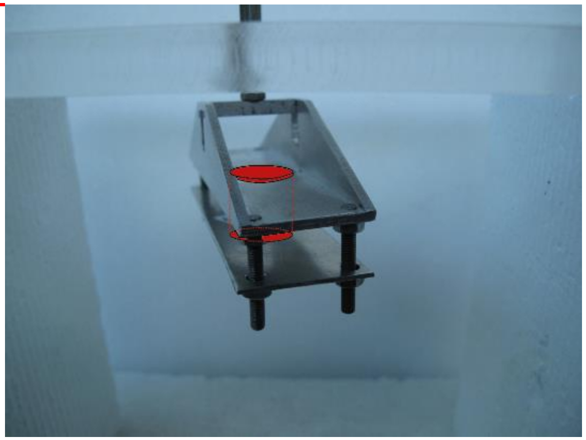


Initial core → Extracted samples → Saturation → Optimization → Finished samples

Material and method

- Convective drying test
  - Sample weighed every 30 seconds in the convective dryer

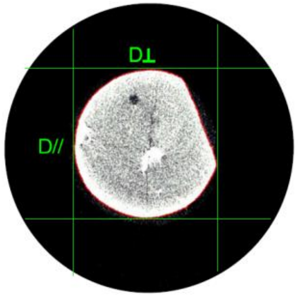


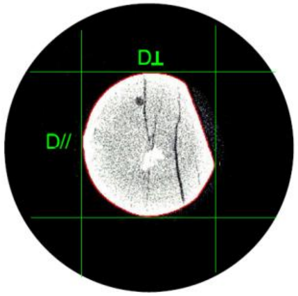


Drying conditions	
Temperature	25°C
Humidity	3,5 %
Air flow	0,8 m/s

MATERIAL AND METHOD

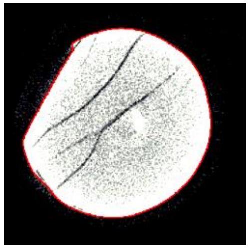
- Data acquisition and image processing
  - Shrinkage and cracking measurement





Identification of the bedding direction → Dimensions at saturated state → Dimensions until dry state

Skyscan 1172



Hole filling and binarization

Summary of the presentation

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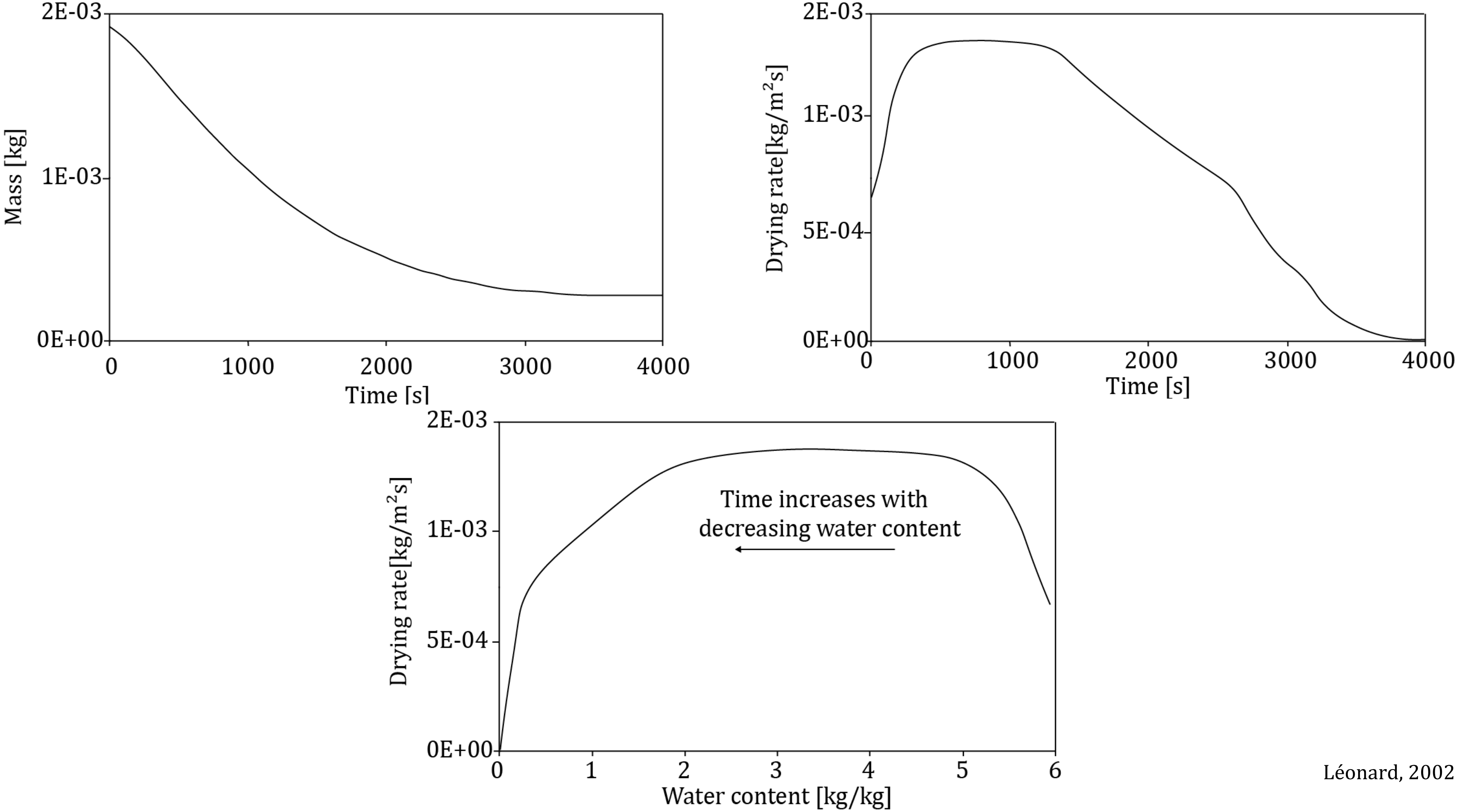
- Shrinkage
- Conclusion

DRYING KINETICS

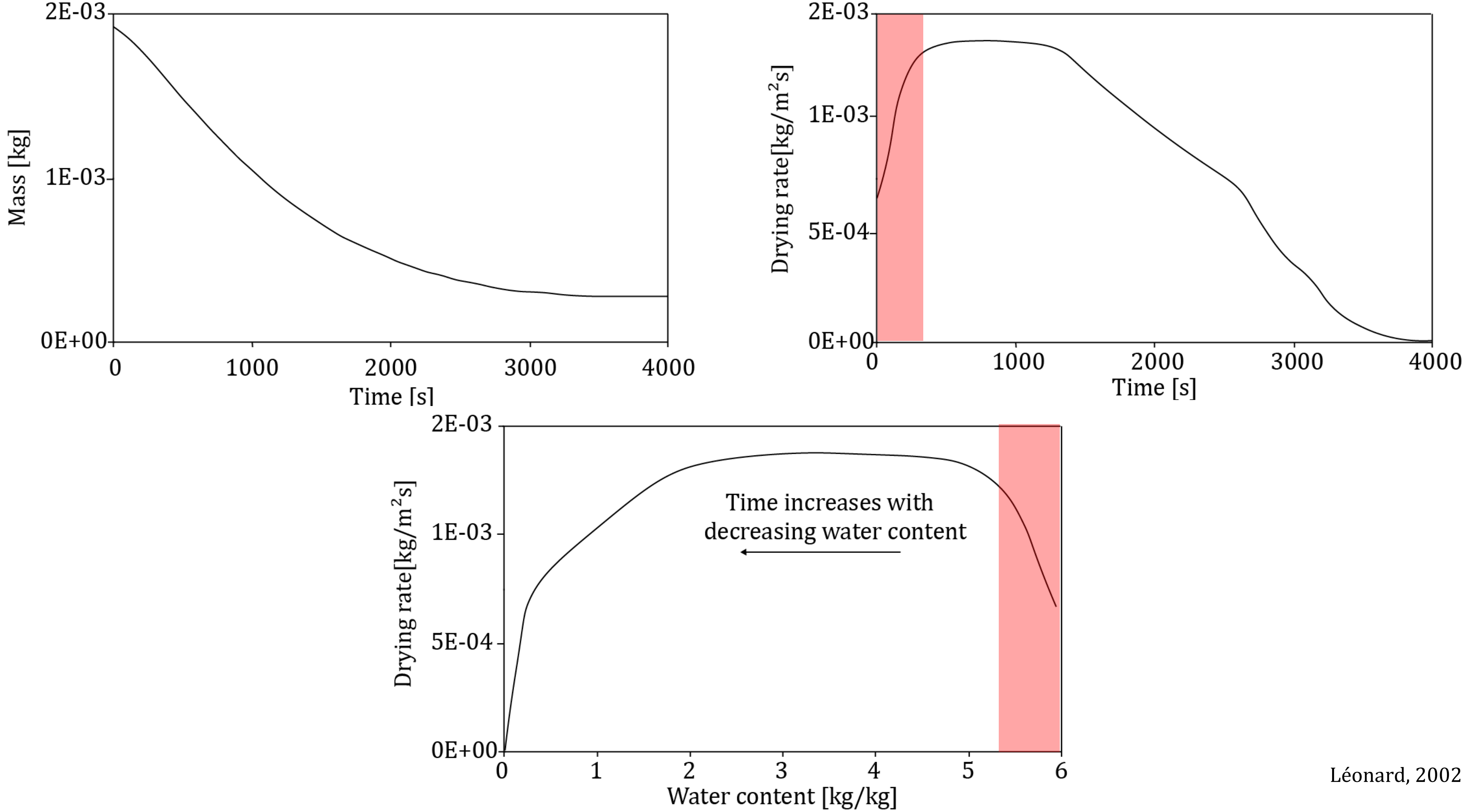
- Theory of porous media drying kinetics



Léonard, 2002

DRYING KINETICS

- Theory of porous media drying kinetics



Léonard, 2002

DRYING KINETICS

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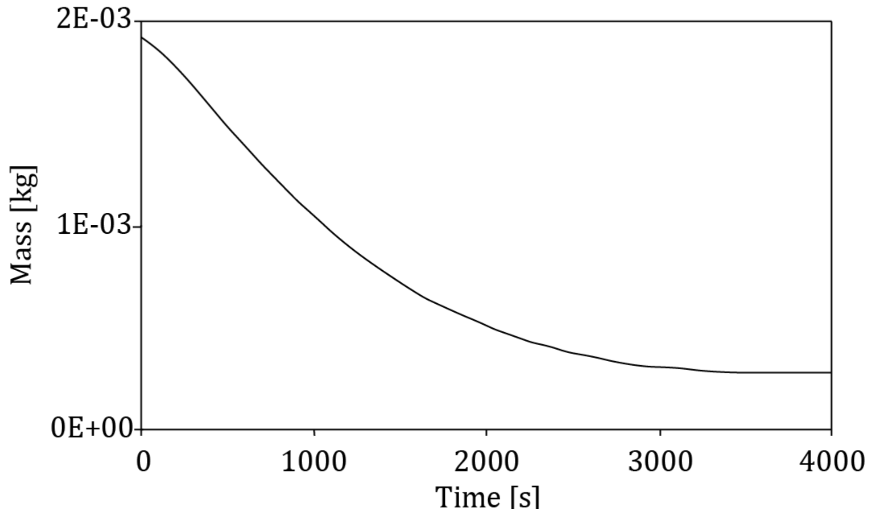

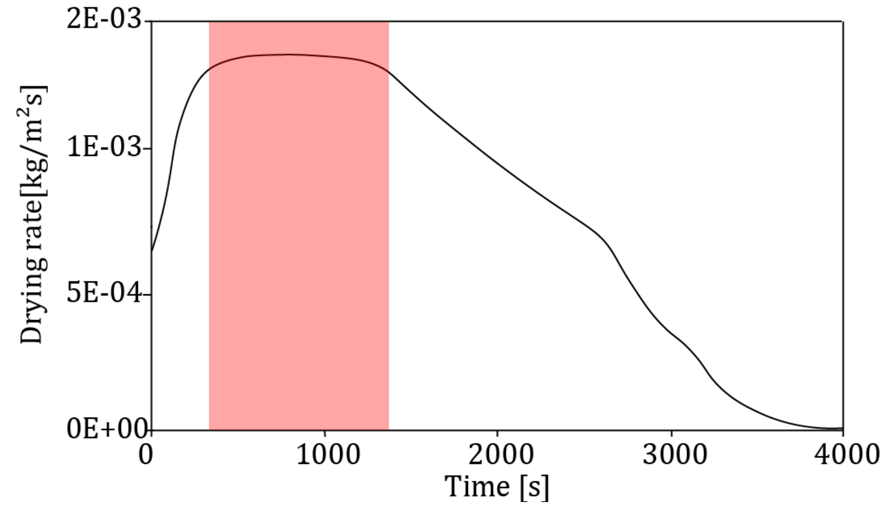

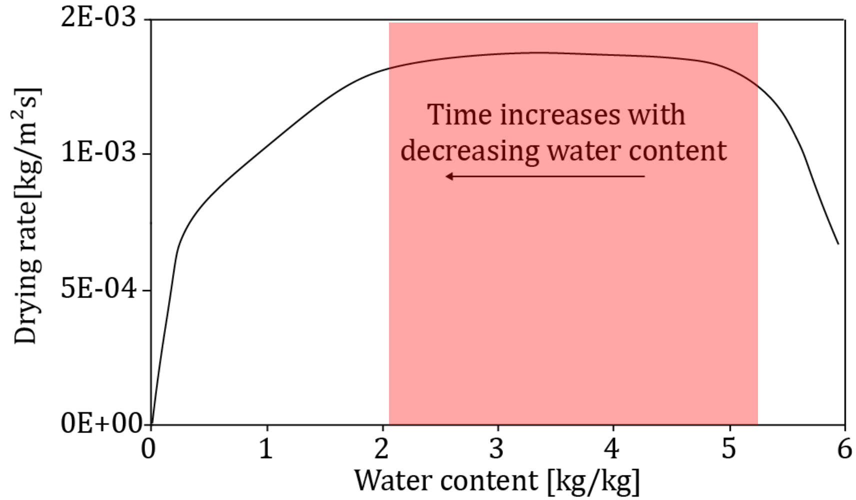

Léonard, 2002

DRYING KINETICS

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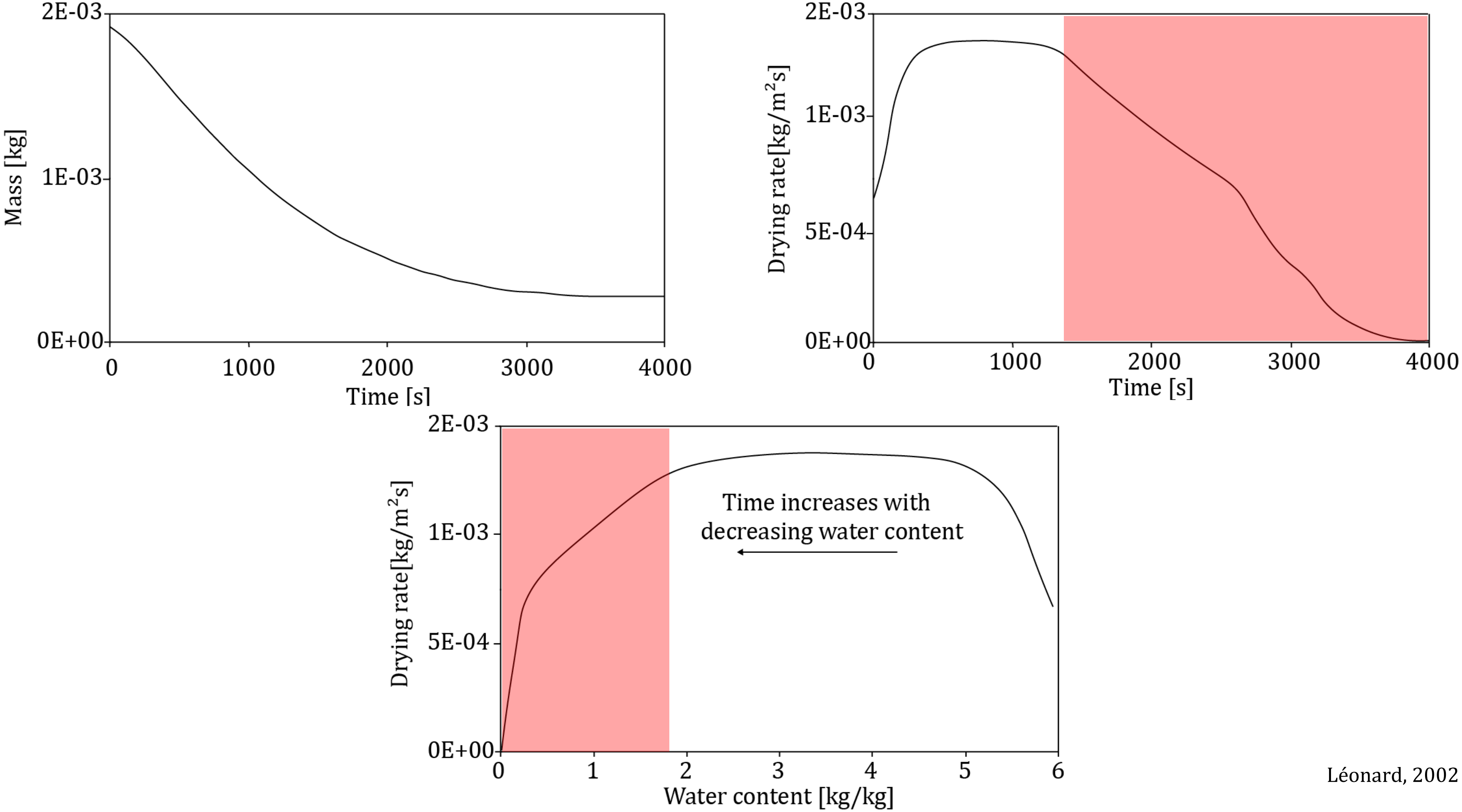
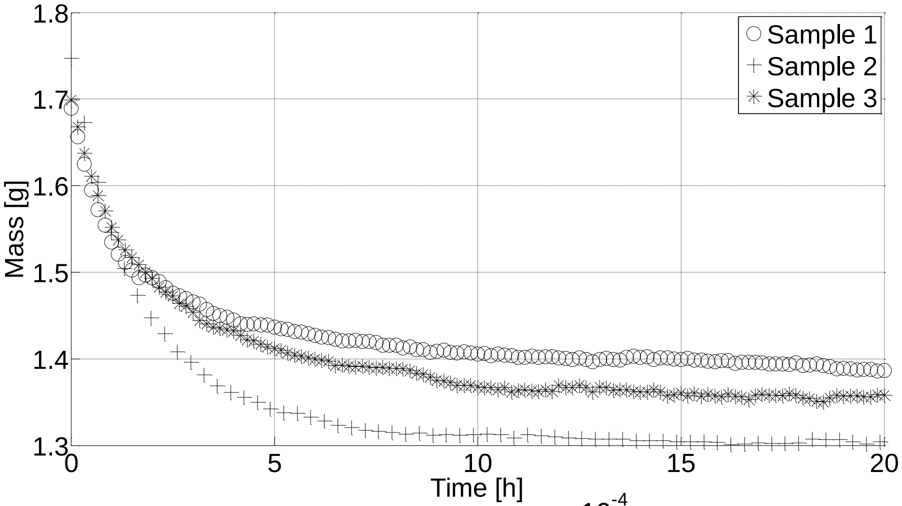
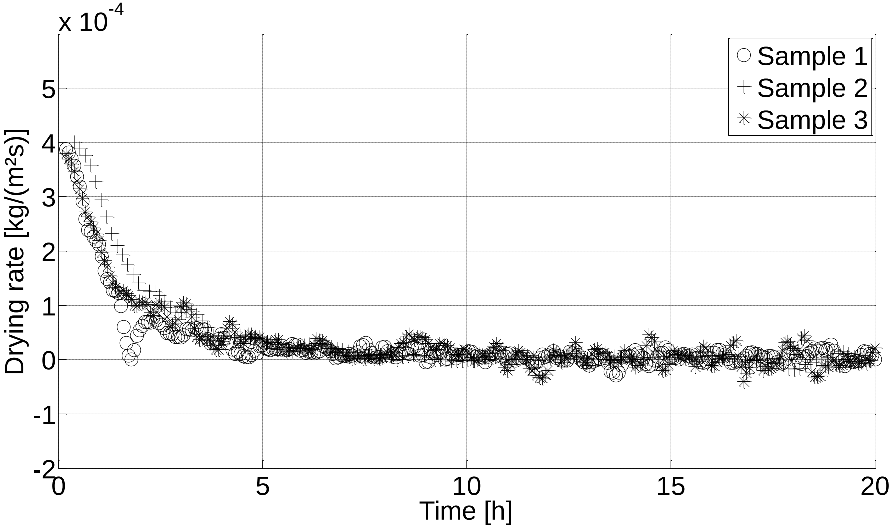


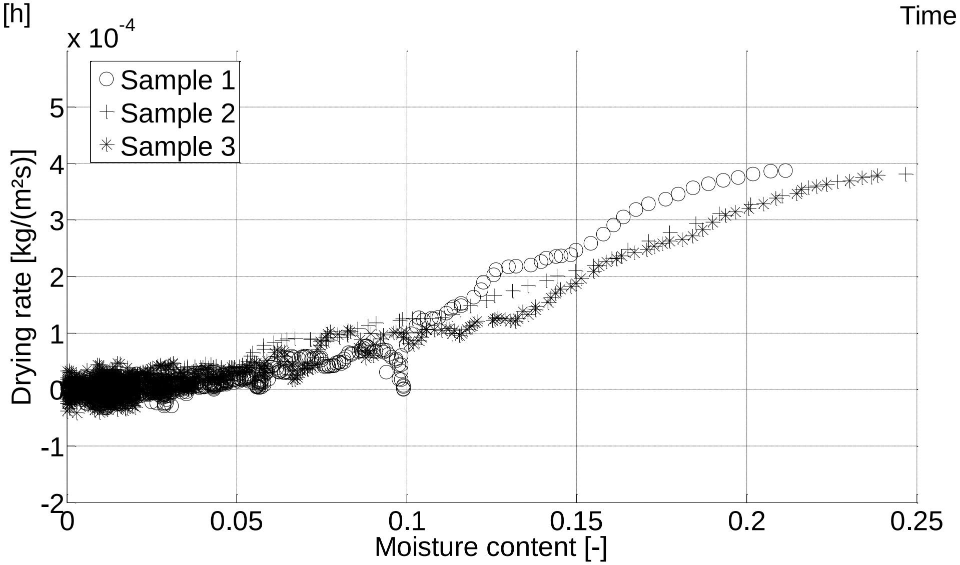
Léonard, 2002

DRYING KINETICS

- Experimental results

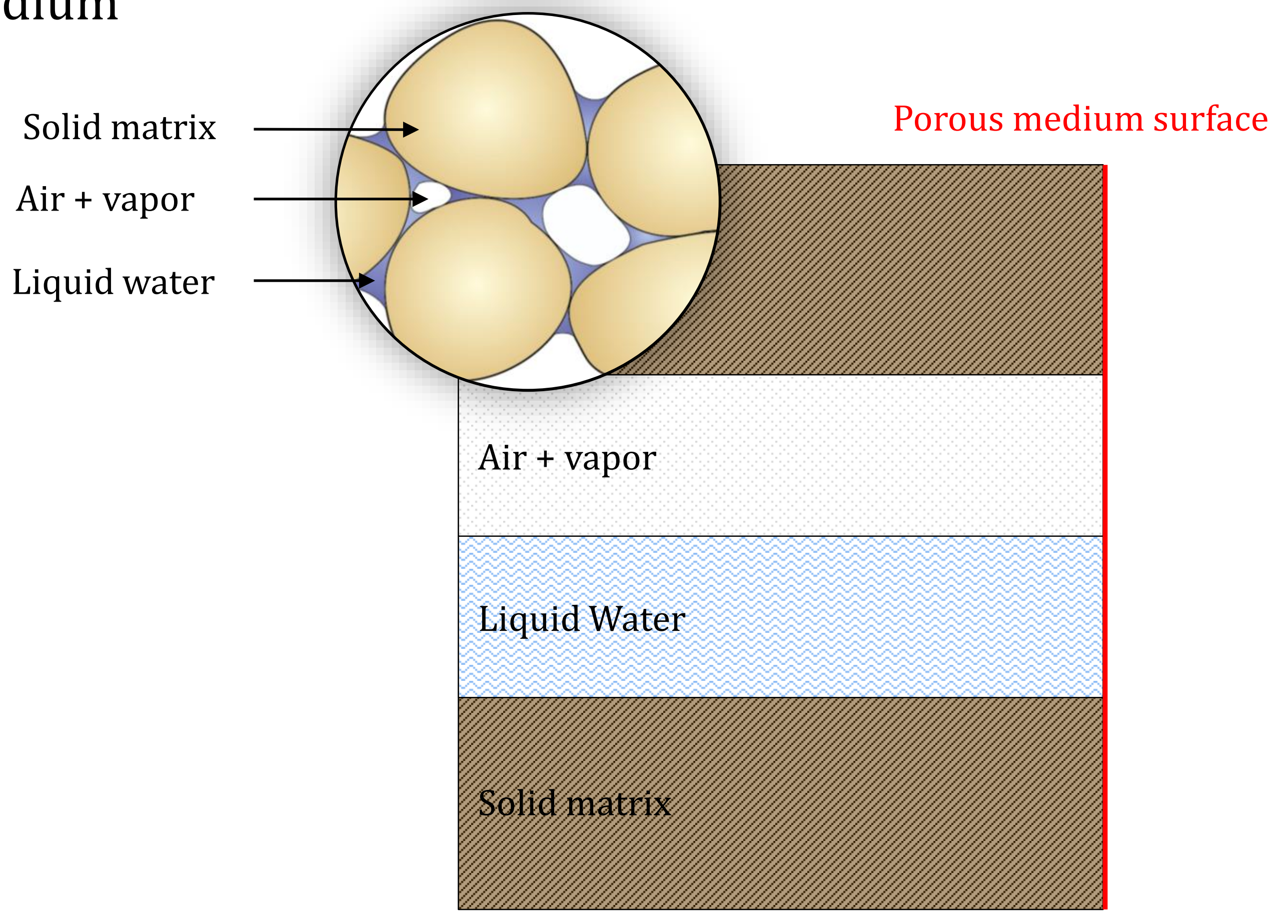






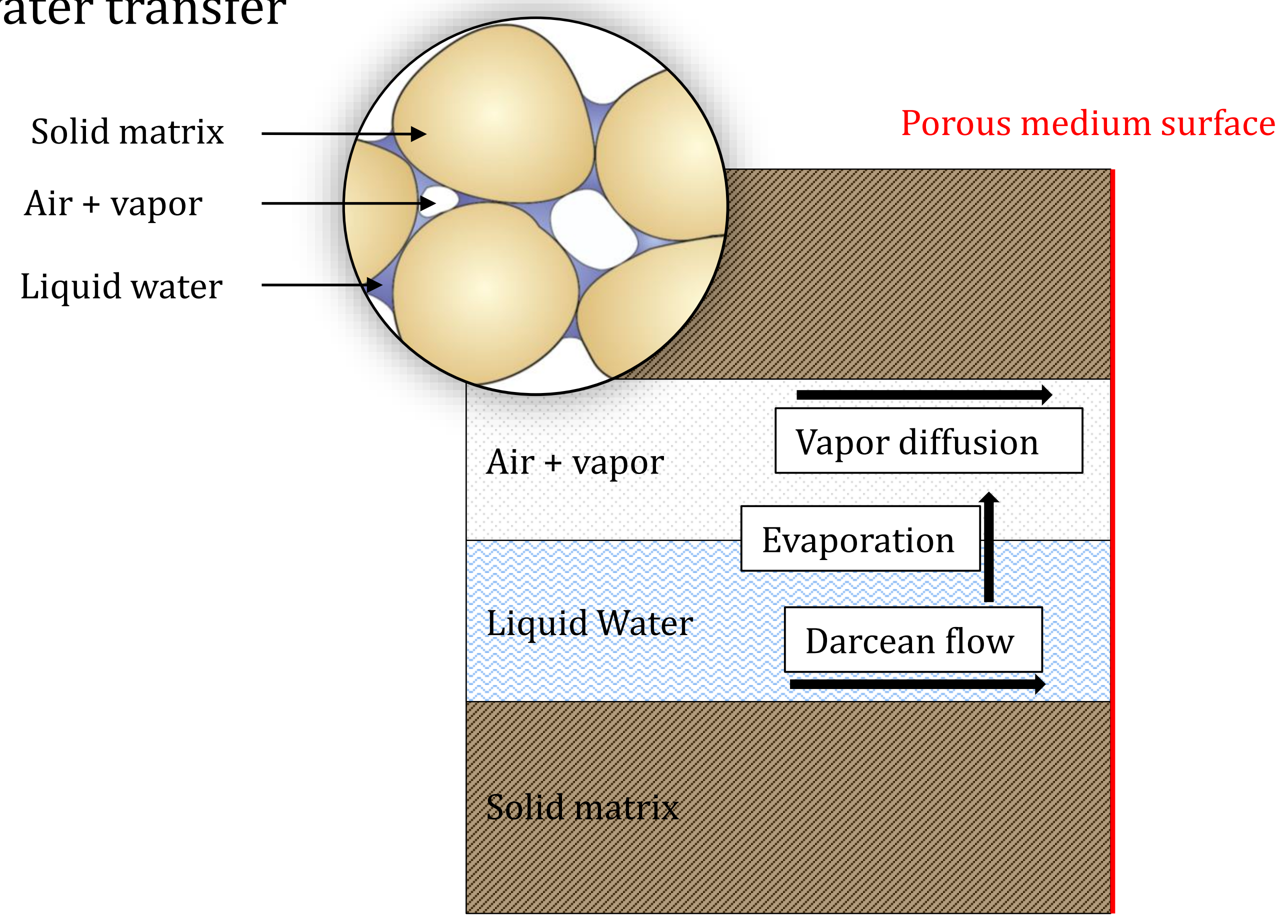
DRYING KINETICS

- Porous medium



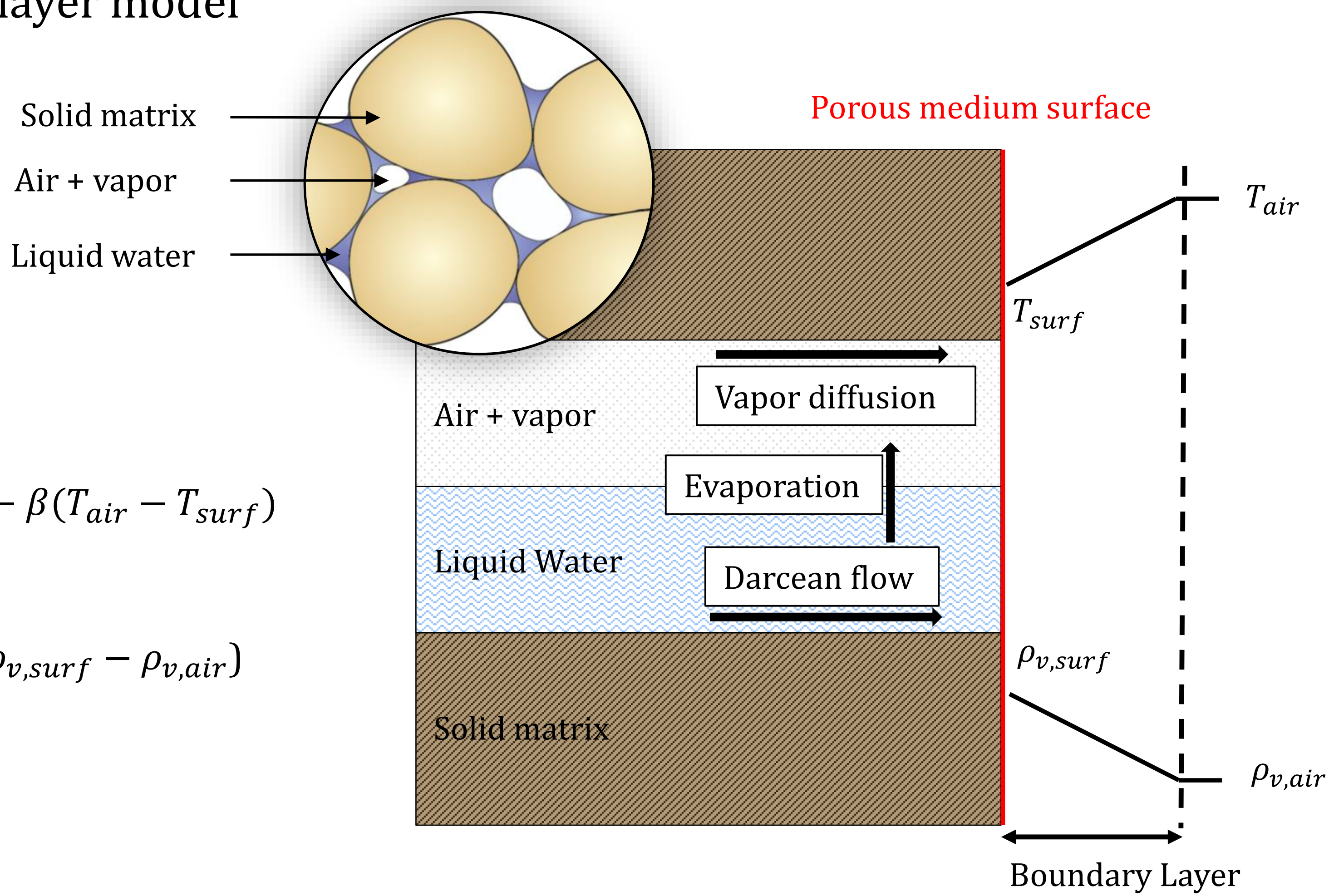
DRYING KINETICS

- Internal water transfer



DRYING KINETICS

- Boundary layer model



Heat flux :

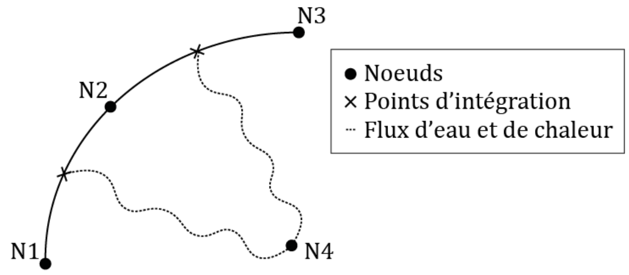
$$q_h = Lq_w - \beta(T_{air} - T_{surf})$$

Water flux :

$$q_w = \boldsymbol{\alpha}(\rho_{v,surf} - \rho_{v,air})$$

NUMERICAL STUDY OF THE DRYING KINETICS

- **Integration** of **limit layer model** into a **FEM framework** :
  - Use of a special kind of finite element :



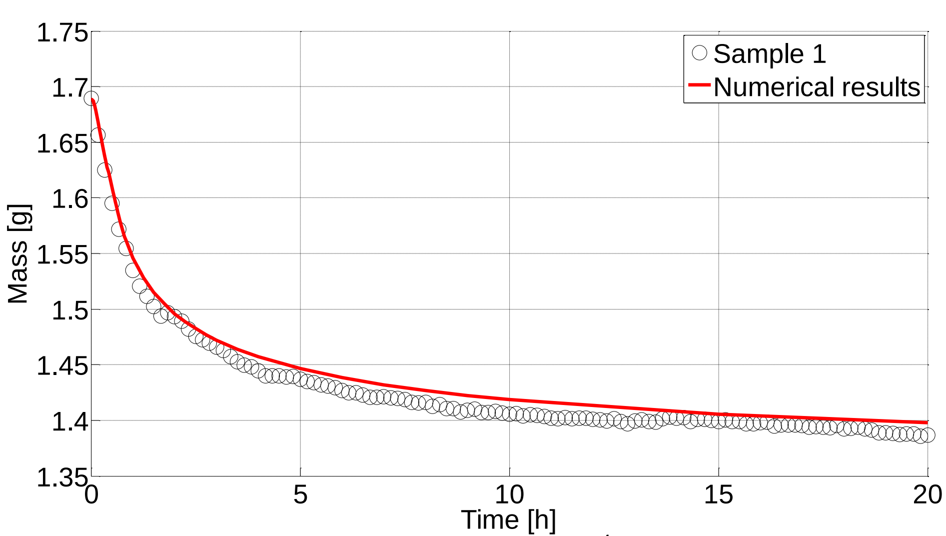
Gerard & al, 2008

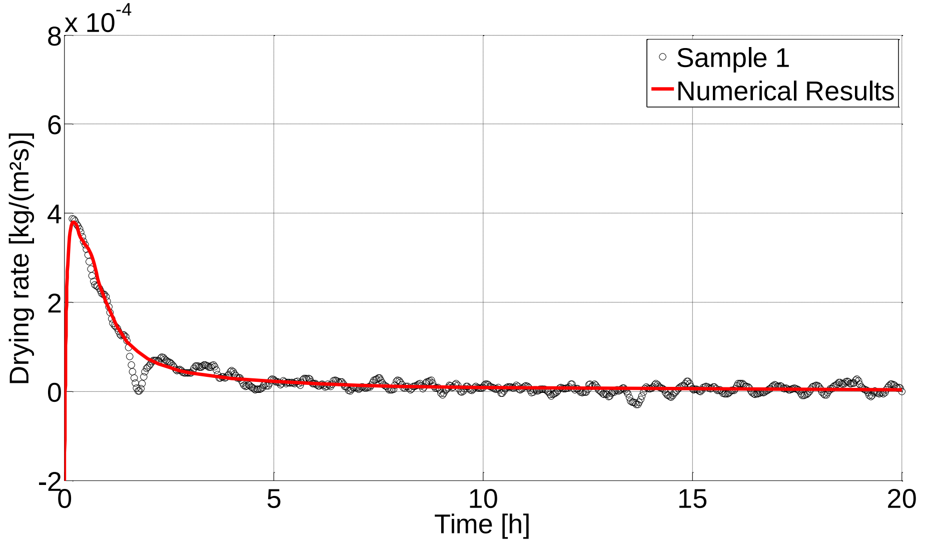
- Boundary conditions
  - **Water pressure** at the environment node : $p_c = -\frac{\rho RT}{M} ln(HR)$
  - **Temperature** at the environment node : $T = 25°C$
  - Transfer coefficients :

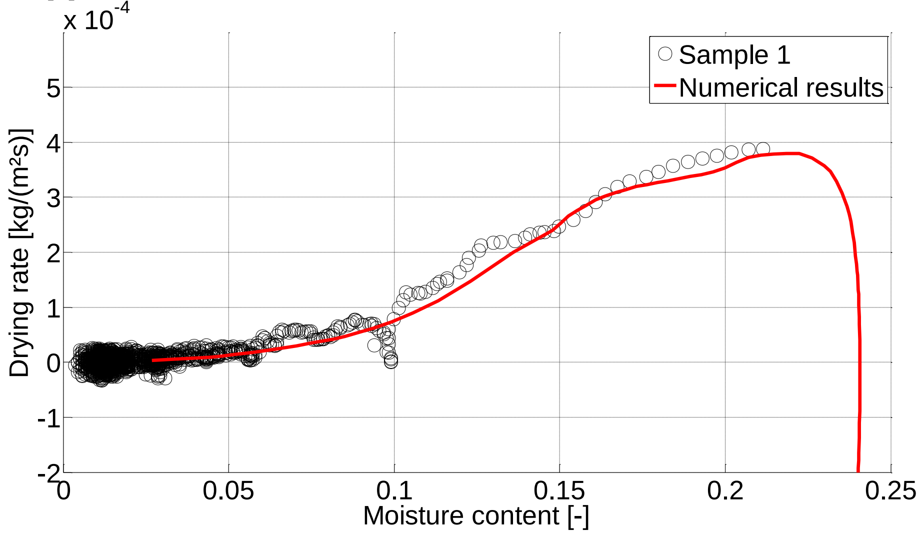
α [m/s]	β [$W/m^2/K$]
0.048	53

Numerical study of the drying kinetics

- Numerical results:







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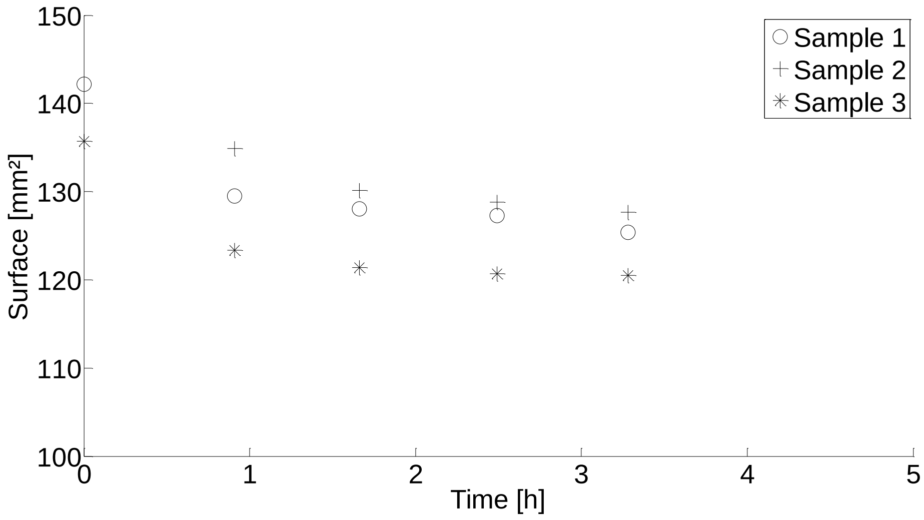
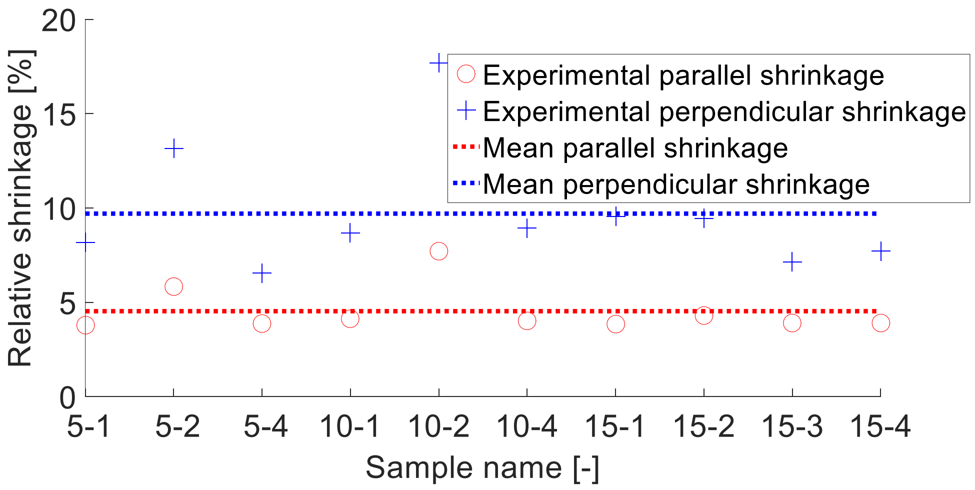
DRYING SHRINKAGE

- Experimental results

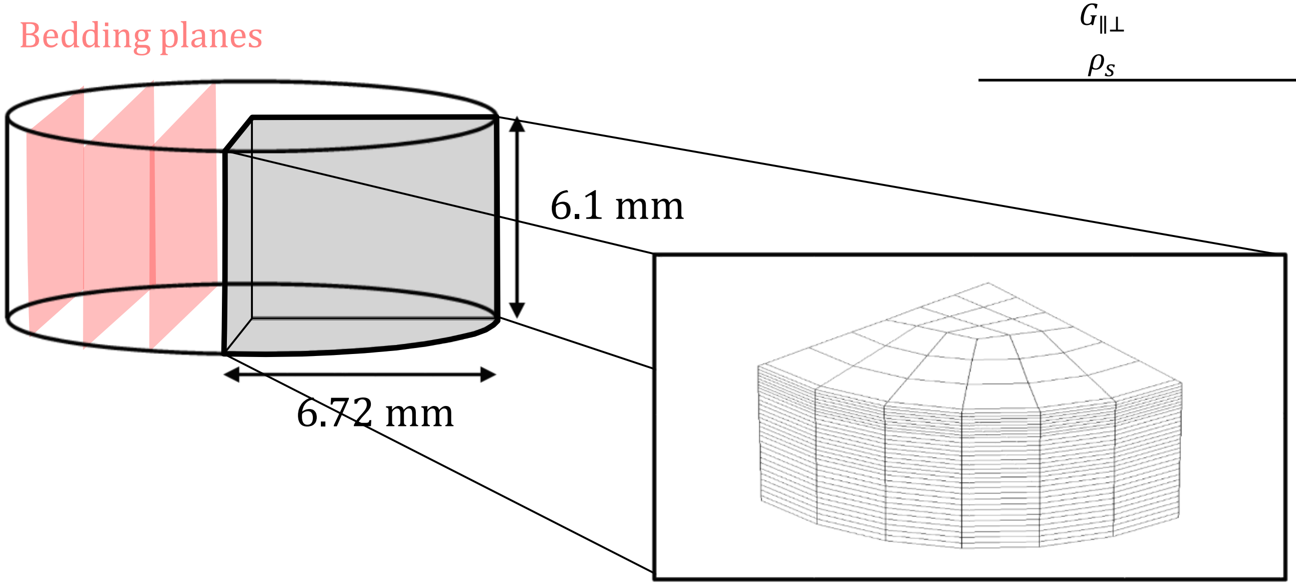




Numerical study of the drying shrinkage

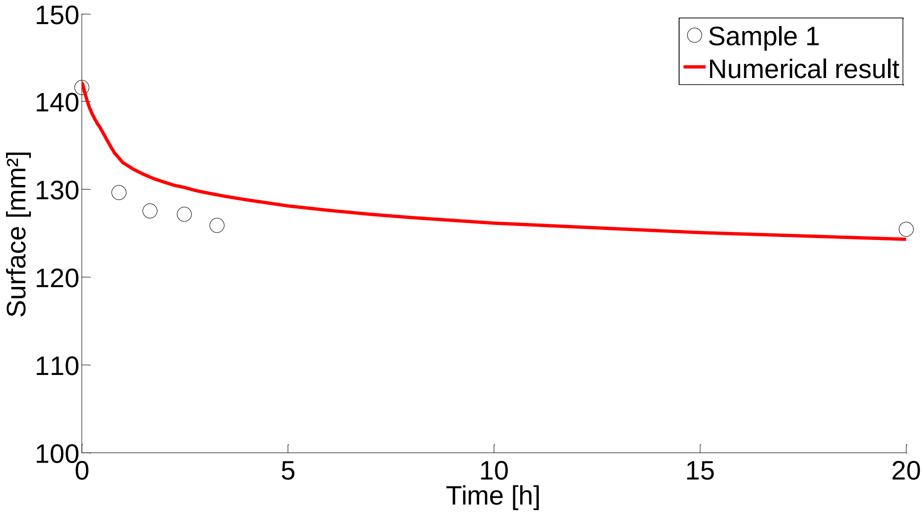
- Numerical mechanical model
  - 3D Orthotropic hydro-mechanical model

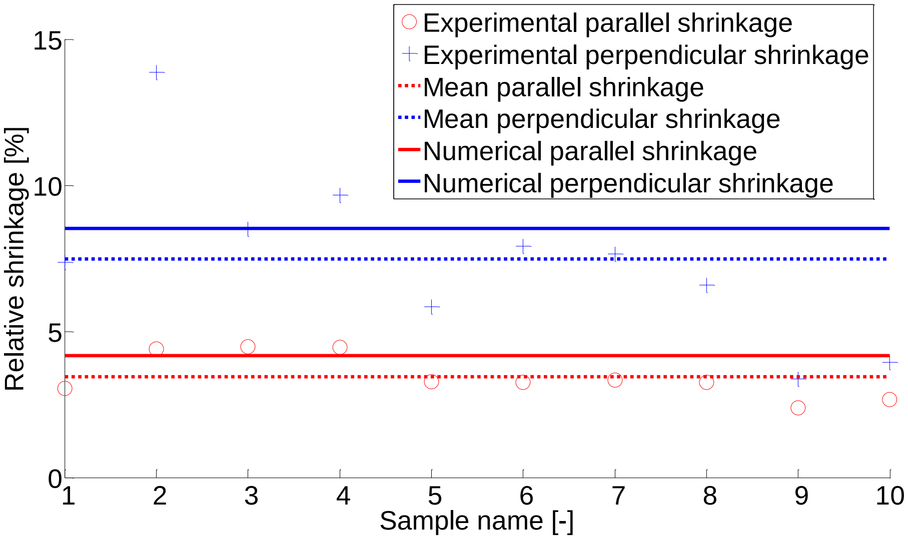
Mechanical Parameters (*Dizier, 2011*)		
$E_{\parallel}$	700	$[MPa]$
$E_{\perp}$	350	$[MPa]$
$\nu_{\parallel\parallel}$	0.25	$[-]$
$\nu_{\parallel\perp}$	0.125	$[-]$
$G_{\parallel\perp}$	1.4	$[MPa]$
ρ_s	2670	$[kg/m^3]$



Numerical study of the drying shrinkage

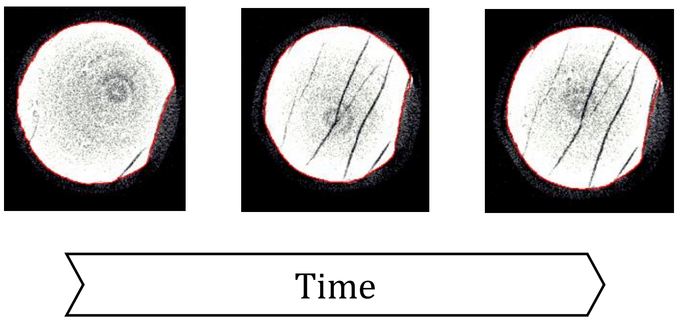
- Numerical results

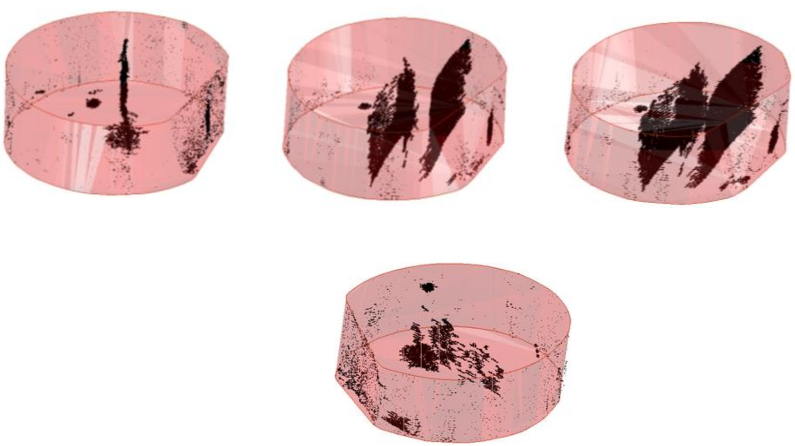


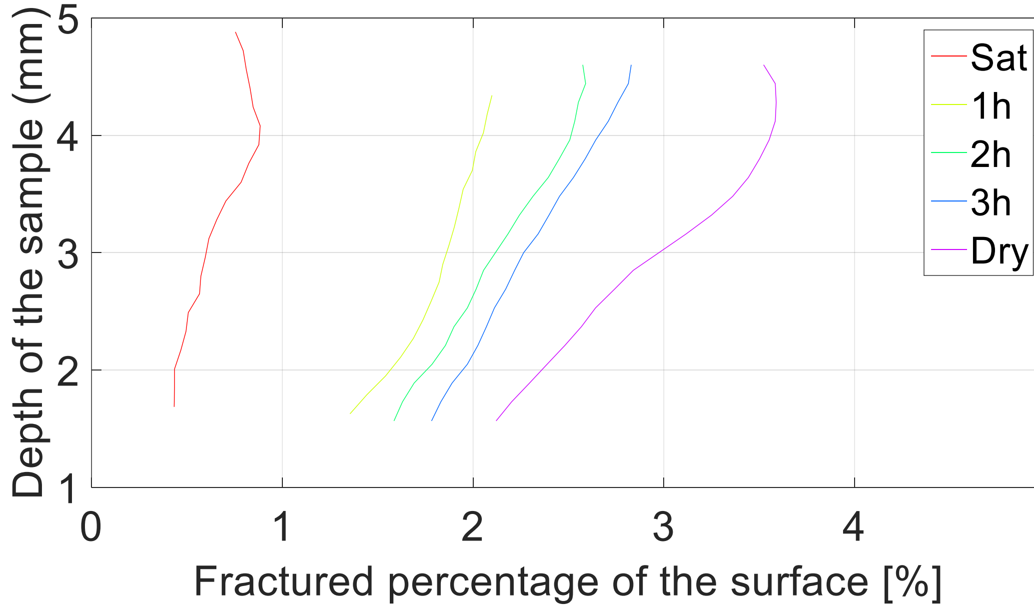


CONCLUSION

- Dessication cracking







References

Andra (2005a). Dossier 2005 Argile. Synthesis: Evaluation of the feasibility of a geological repository in an argillaceous formation, Meuse/Haute Marne site. Technical report, Paris, France.

Bastiens W., Demarche M., 2003. The extension of the URF HADES: realization and observation. Proceedings of the WN'03 Conference, Tucson, USA.

Craeye B., De Schutter G., Van Humbeeck H., Van Cotthem, 2009. *Early age behaviour of concrete supercontainers for radioactive waste disposal.* Nuclear Engineering and Design, 239, 23-35.

Gerard P., Charlier, R, Chambon, R, & Collin, F. 2008. Influence of evaporation and seepage on the convergence of a ventilated cavity. Water resources research, 44(5), W00C02.

Léonard A., Étude du séchage convectif de boues de station d'épuration. Suivi de la texture par microtomographie à rayons X. Thèse de doctorat, Université de Liège, Faculté des Sciences appliquées, 2003.

SCK-CEN. R and D for the geological disposal of medium and high level waste in the Boom clay, 2009. URLence.sckcen.be/en/Projects/Project/RD_waste_disposal/Geological_disposal.

Thank you !

This work was possible thanks to the FRS-FNRS

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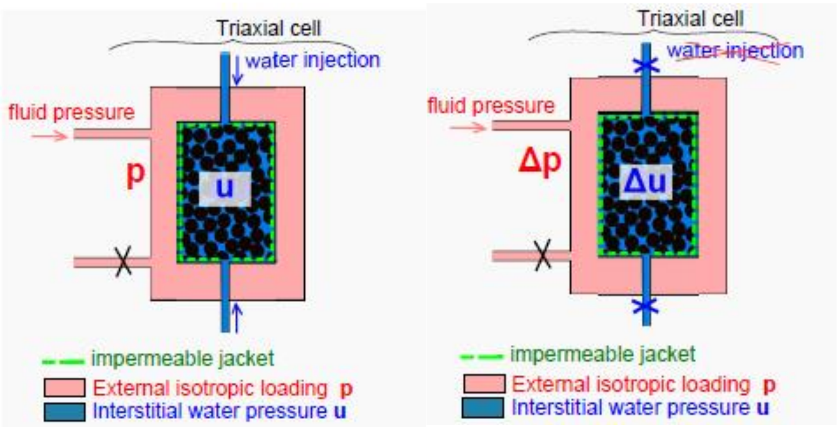
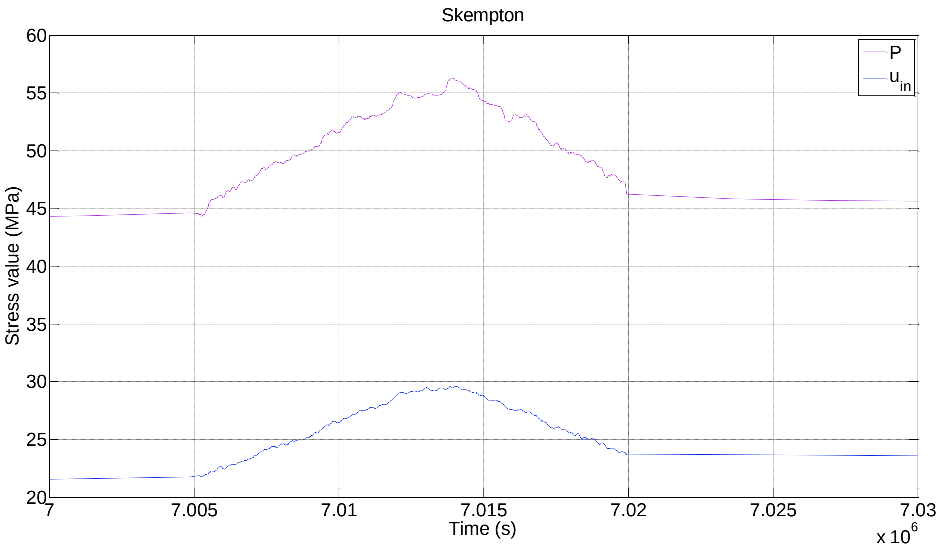
Saturation Control

- Skempton coefficient





MATERIALS AND METHODS

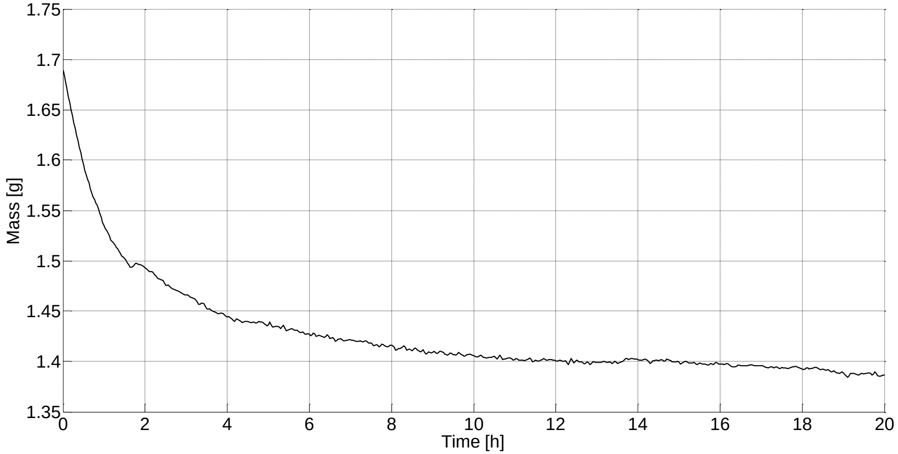
- X-Ray tomography characteristics
  - Cross section acquisition using a X-Ray microtomography

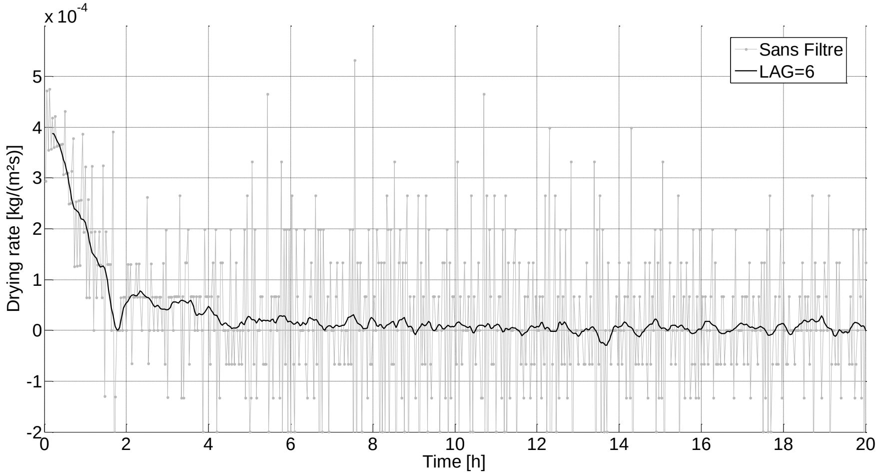
Skyscan 1172

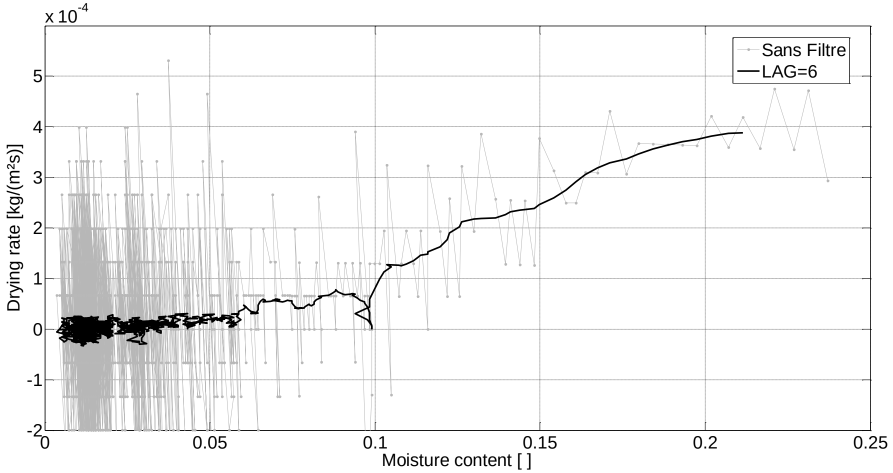
Source Voltage = 100 kV	Filter = Al 0.5 mm	4x4 binning = 900x666 pixel radiograms
Pixel size = 27.27 µm	Exposure time = 510 ms	Rotation Step (deg)= 0.65
180° rotation	2 vertically-connected scans	Scan duration = 8 minutes

Experimental results

- Numerical filter

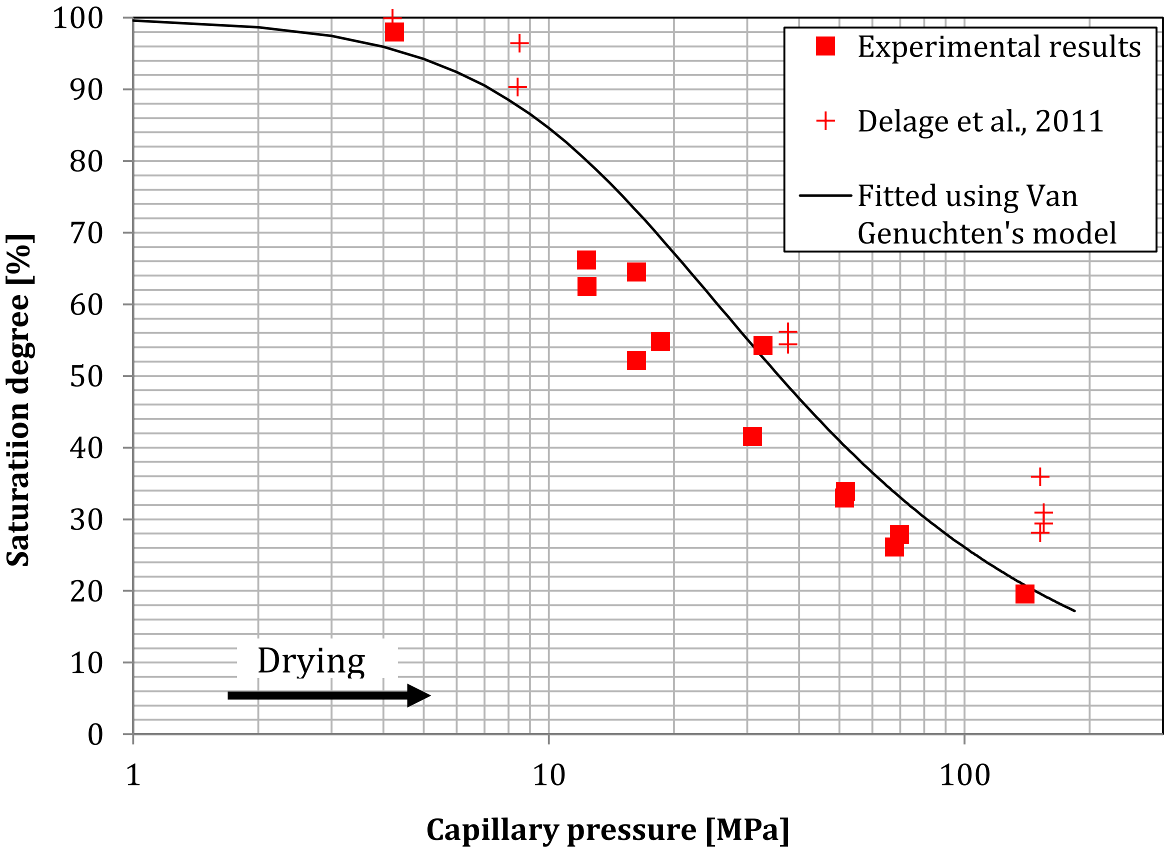






WATER RETENTION CURVE

- Samples put into chamber with controlled suction (saline solution)
- Water content measured ⇒ saturation degree deduced



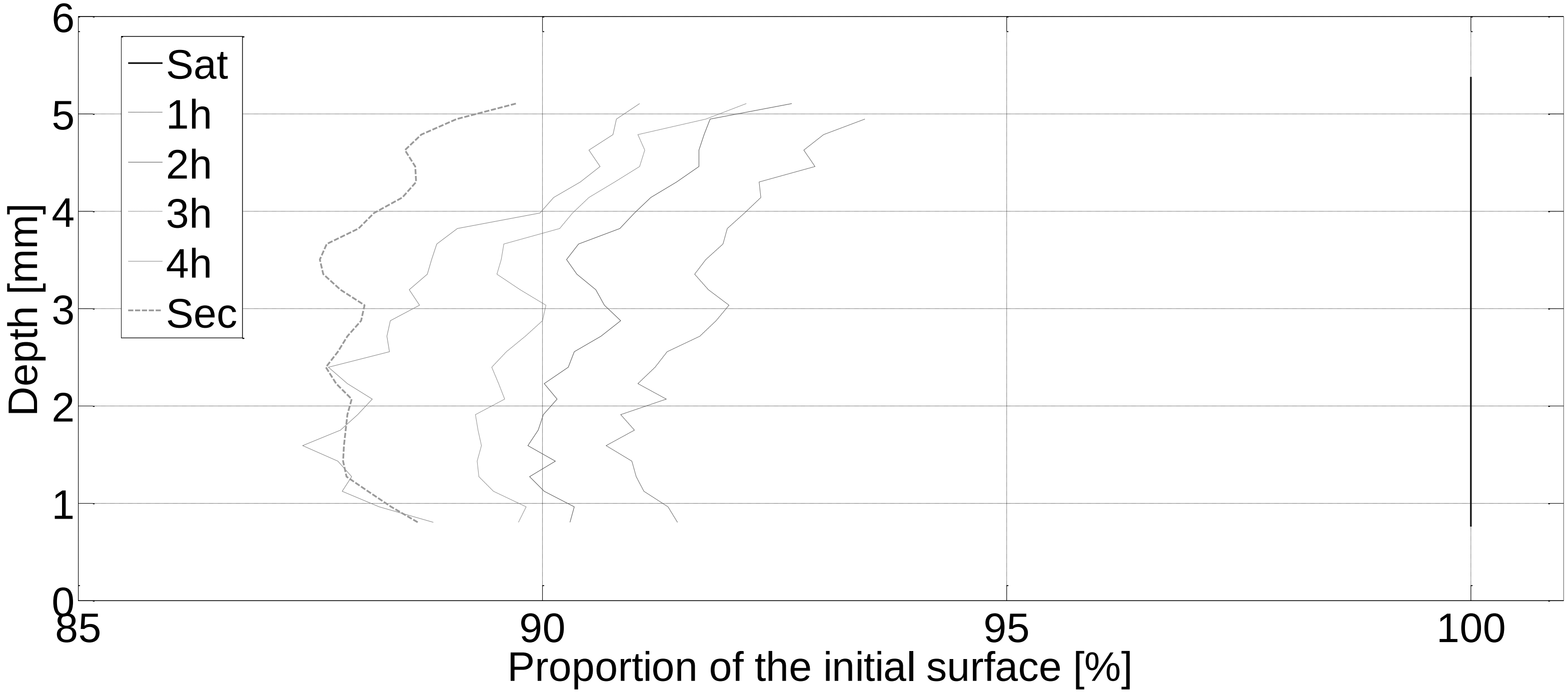
Van Genuchten formulation :

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

VAN GENUCHTEN FORMULATION		
S_{res}	0	[-]
S_{sat}	1	[-]
α_{vg}	15	$[MPa]$
m_{vg}	0.449	[-]
n_{vg}	1.70	[-]

Drying Shrinkage

- Quickly homogeneous on the whole sample



NUMERICAL STUDY

- Parameters used :

PARAMETERS	VALUES	UNITS
	HYDRAULIC PARAMETERS	
$k_{sat,\perp}$	8.10^{-12}	[m/s]
$k_{sat,\parallel}$	2.10^{-12}	[m/s]
n	0.39	[-]
	MECHANICAL PARAMETERS	
$E_{\parallel}$	700	$[MPa]$
$E_{\perp}$	350	$[MPa]$
$\nu_{\parallel\parallel}$	0.25	$[-]$
$\nu_{\parallel\perp}$	0.125	$[-]$
$G_{\parallel\perp}$	1.4	$[MPa]$
ρ_s	2670	$[kg/m^3]$
	THERMAL PARAMETERS	
c_s	2080	$[\frac{J}{kg*K}]$
ρ_s	2670	$[kg/m^3]$
c_w	4185	$[\frac{J}{kg*K}]$
ρ_w	1000	$[kg/m^3]$
c_a	1004	$[\frac{J}{kg*K}]$
ρ_a	1.2	$[kg/m^3]$

NUMERICAL MODEL

- Thermal model
  - Storage

$$S_T = \underbrace{nS_{r,w}\rho_w c_{p,w}(T - T_0)}_{\text{Liquid water}} + \underbrace{nS_{r,g}\rho_a c_{p,a}(T - T_0)}_{\text{Air}} + \underbrace{nS_{r,g}\rho_v c_{p,v}(T - T_0)}_{\text{Vapor}} + \underbrace{(1 - n)\ \rho_s c_{p,s}(T - T_0)}_{\text{Solid}} + \underbrace{nS_{r,g}\rho_v c_{p,v} L}_{\text{Vapor latent heat}}$$

  - Heat flux

$$V_T = -\underbrace{\Gamma \nabla T}_{\text{Conduction}} + \underbrace{c_{p,w}\rho_w f_w(T - T_0) + c_{p,a}\rho_a f_g(T - T_0) + c_{p,v}(\rho_v f_v + i_v)\ (T - T_0) + (\rho_v f_v + i_v)\mathrm{L}}_{\text{Convection}}$$