COMSOL SETKÁNÍ UŽIVATELŮ

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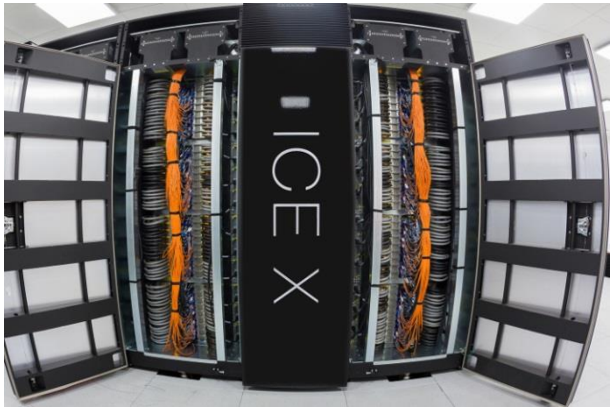
Experimental research

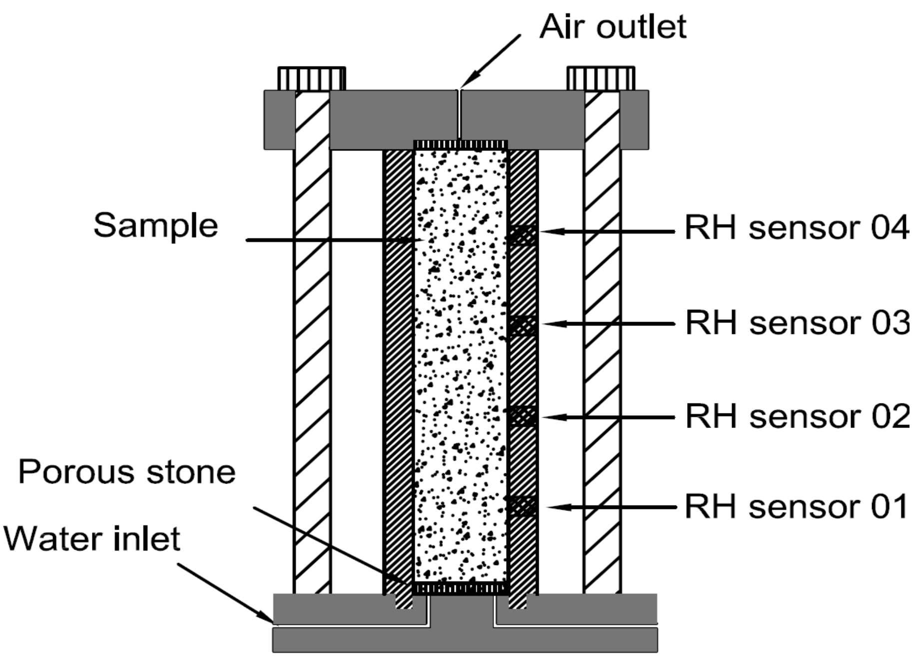
Modelling THM processes

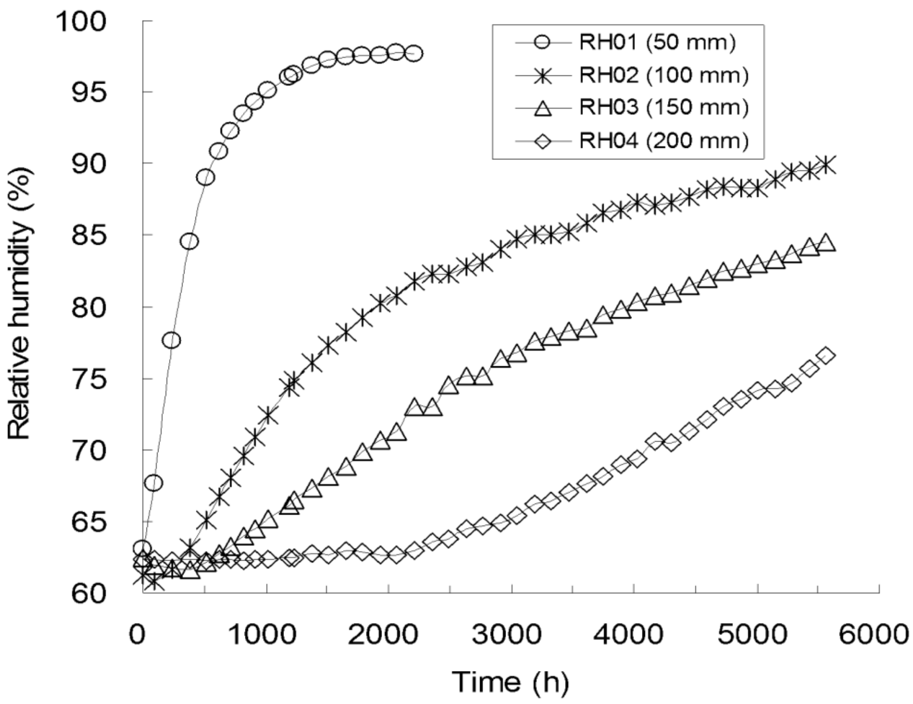
IT4Innovations
department
Institute of Geonics
AS CR Ostrava



Infiltration test

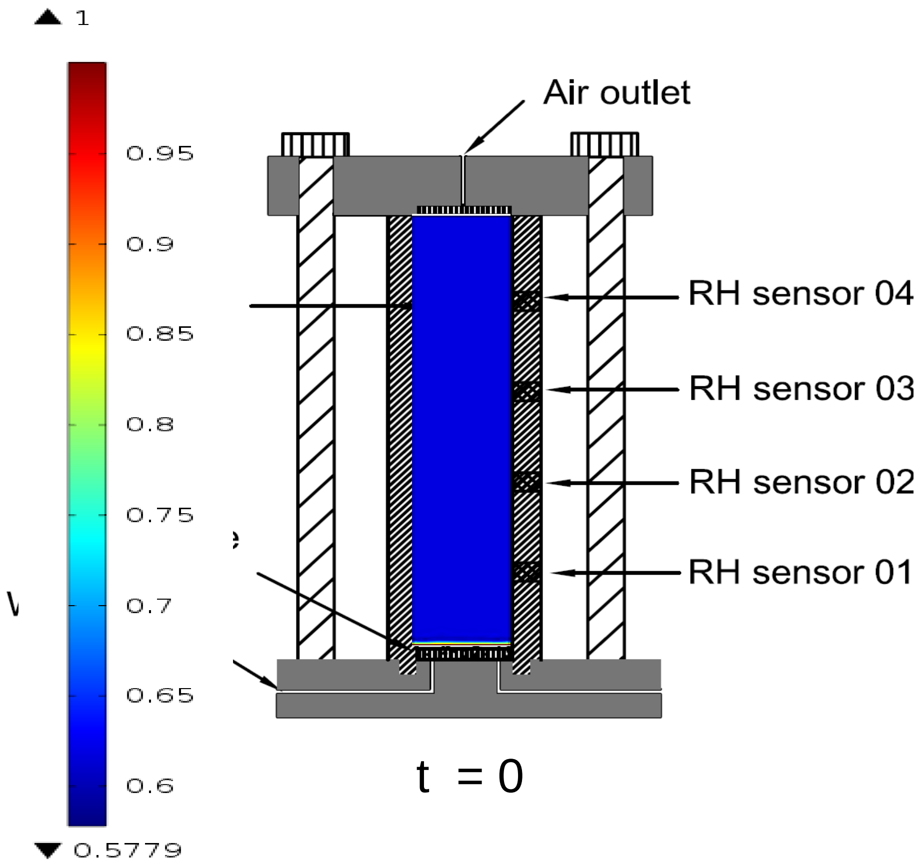
- Focused on modelling of saturation process in bentonite MX-80 under **constant volume condition** (clay and quartz sand in dry weight proportions 70/30). It is mined out in Wyoming.

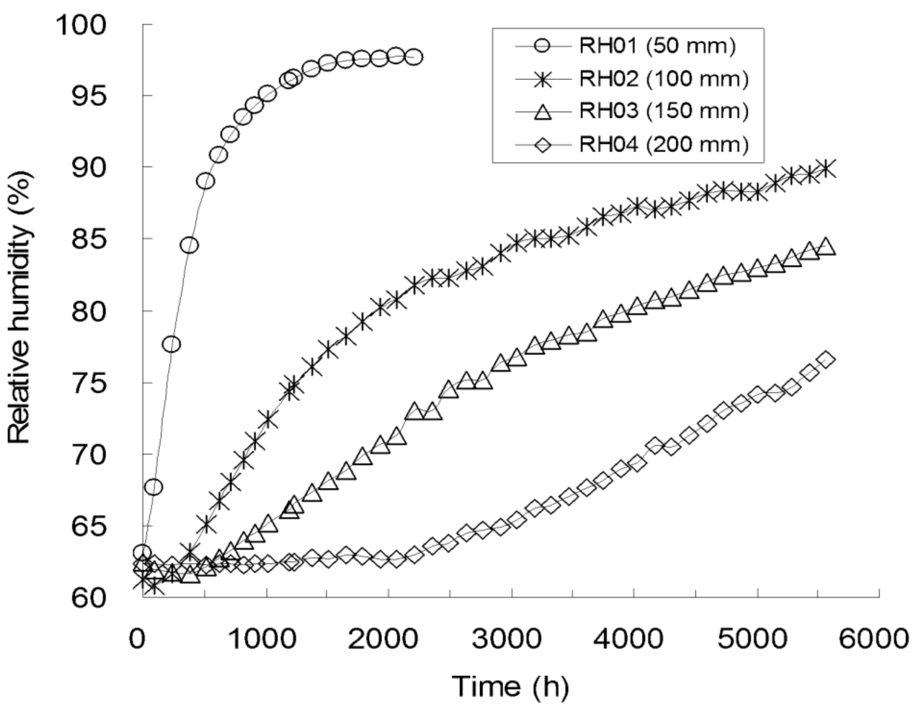




Experiments – Step 0

- Focused on modelling of saturation process in bentonite MX-80 under **constant volume condition.**





Martin Hasal, Hydro-mechanical Modelling of SEALEX Experiments

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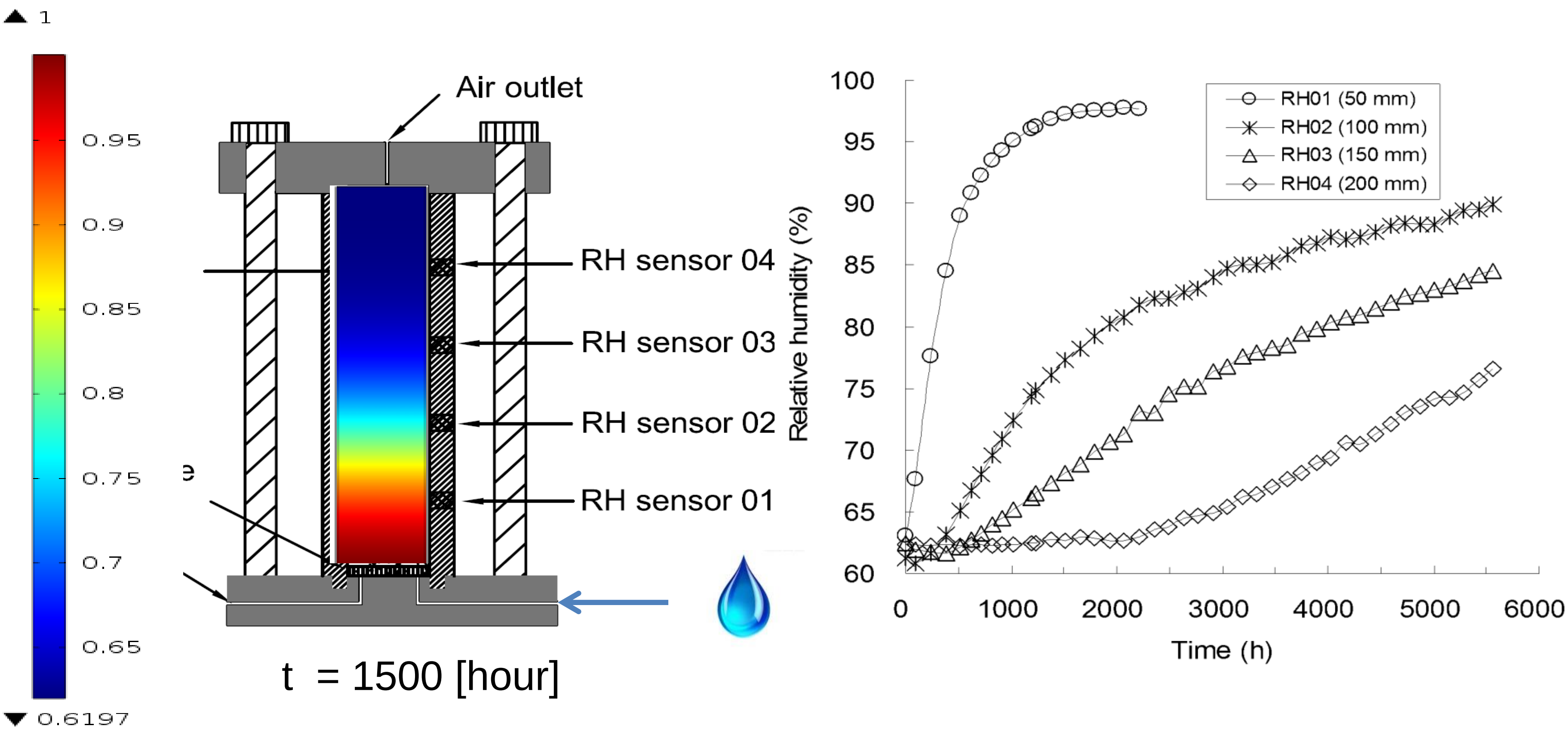

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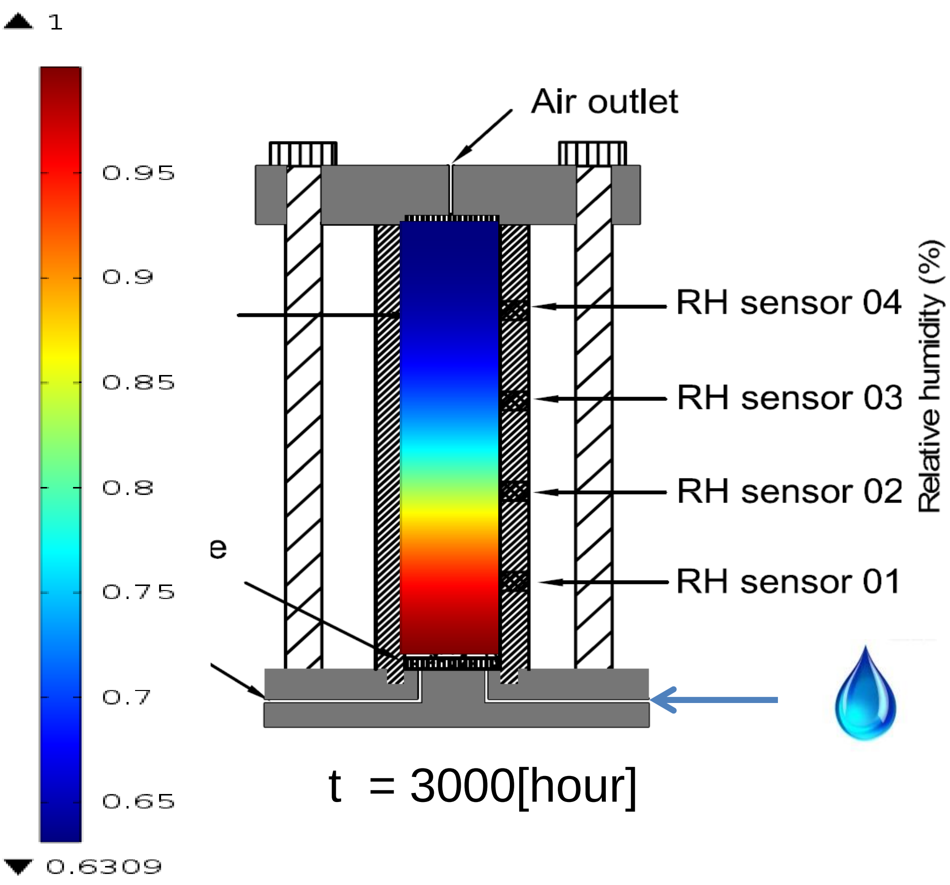

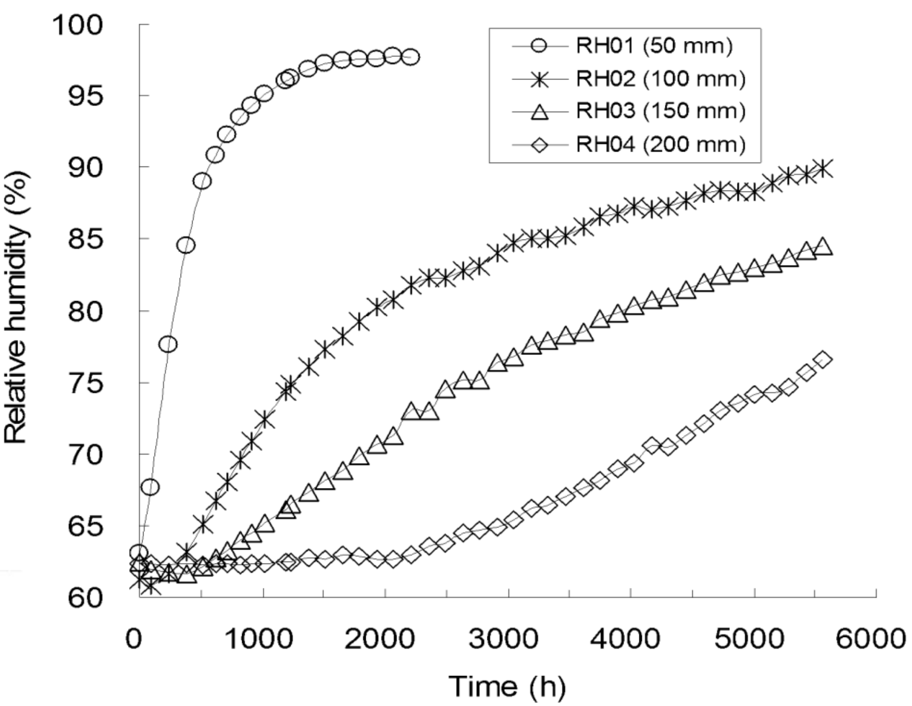

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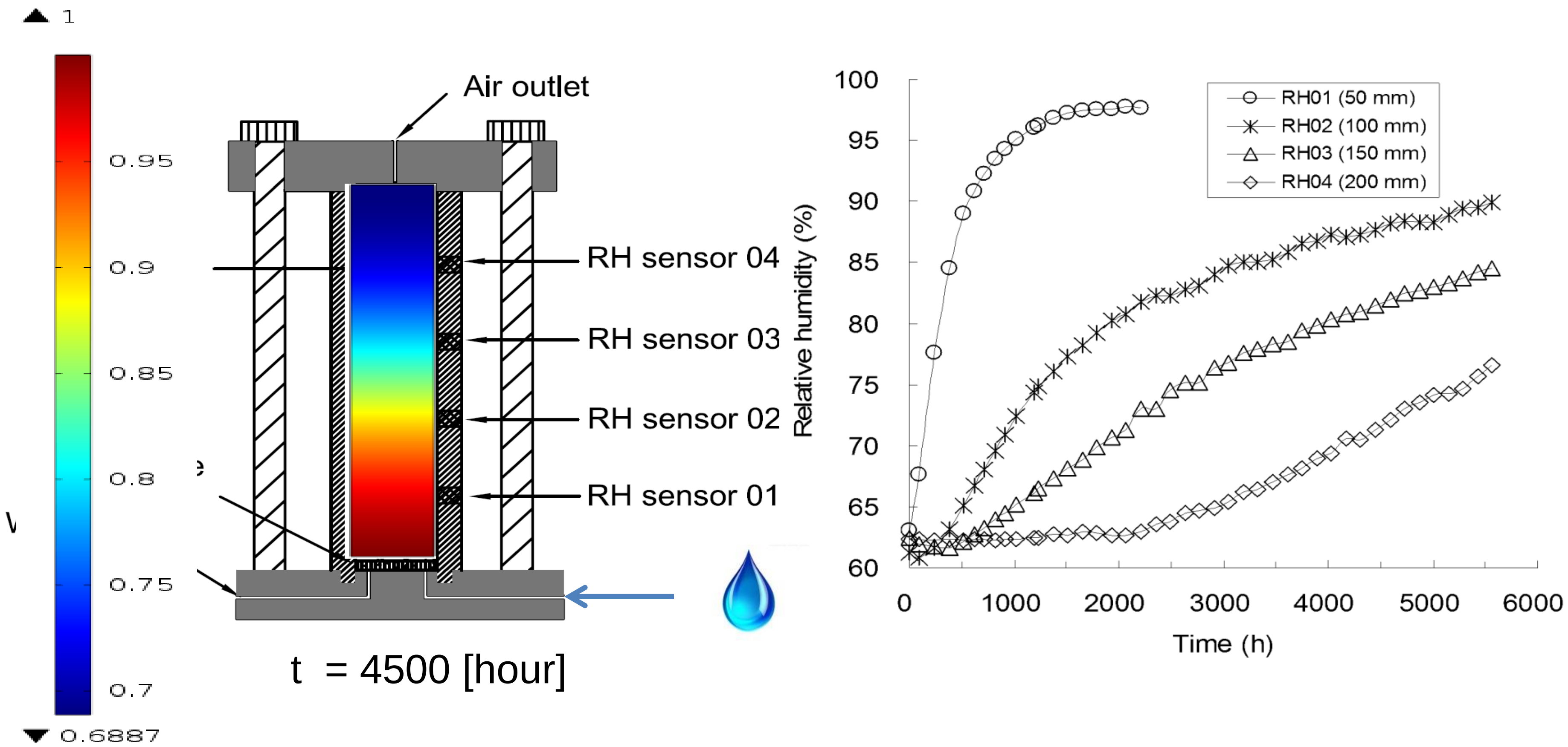

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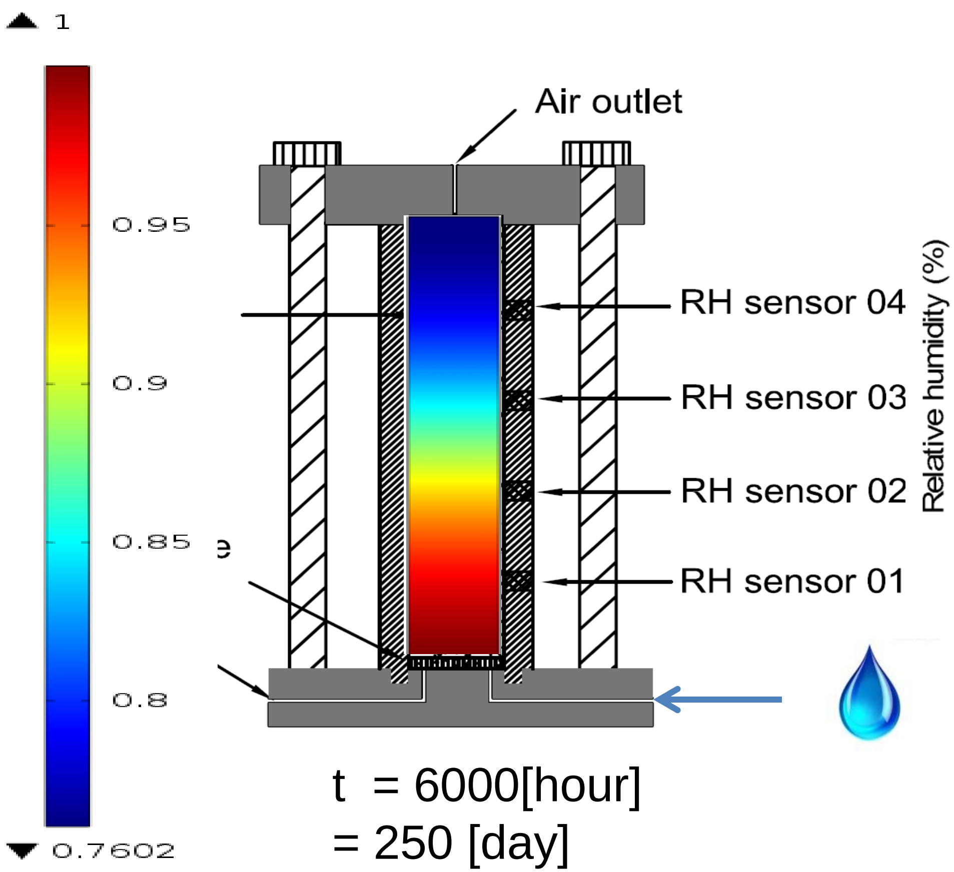
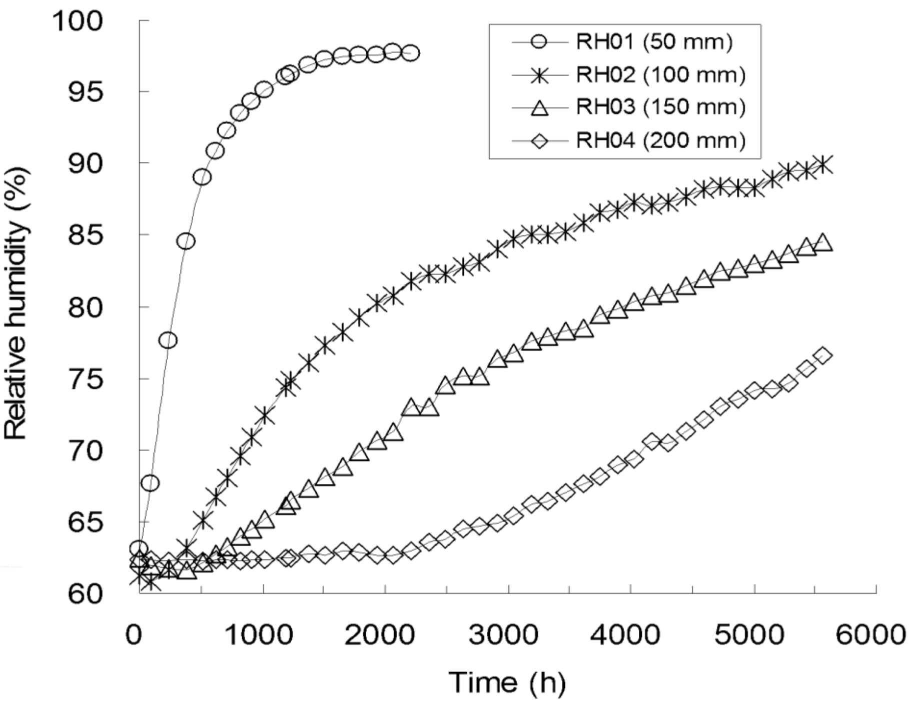
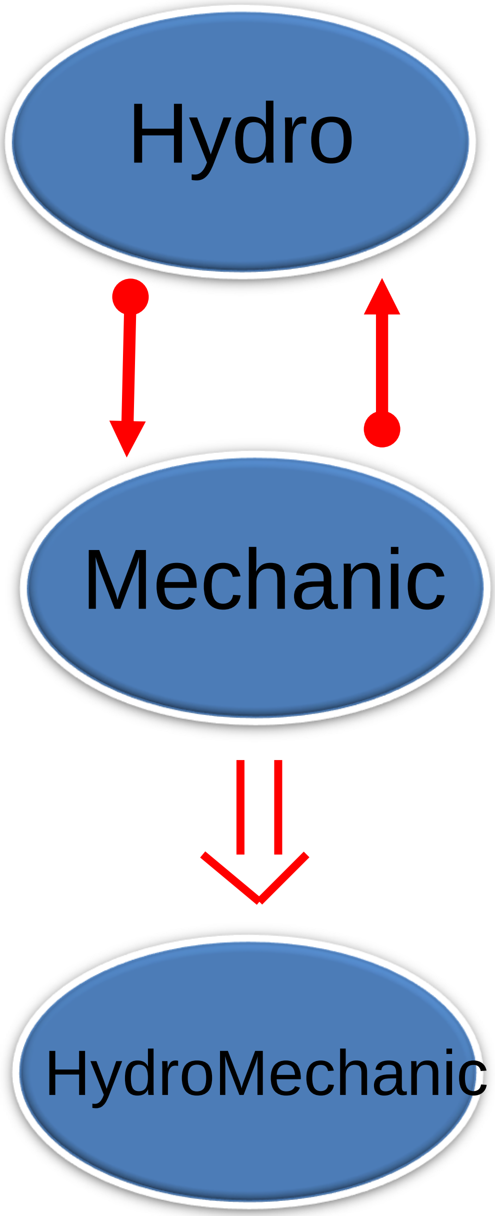


t = 6000[hour]
= 250 [day]



Mathematical model



H unsaturated flow

- Richard’s equation
- inputs: saturated and relative permeability, retention dependence

M Elasticity (linear/nonlinear)

HM coupling implemented COMSOL

- Biot-Bishop model,
  - effective stress, water squeezing due to porosity change
- permeability change (Kozeny),
- retention depending on deformation
- swelling deformation

Richards' equation

- represents the movement of water in unsaturated soils, and was formulated by Lorenzo A. Richards in 1931

$$\frac{\partial(\phi S_w \rho_w)}{\partial t} = \frac{\partial(\theta_w \rho_w)}{\partial t} = \nabla \cdot \left(\rho_w \frac{k_r k_{sat}}{\mu_w} \nabla(p_w + \rho_w g h_e) \right) + \rho_w q_w,$$

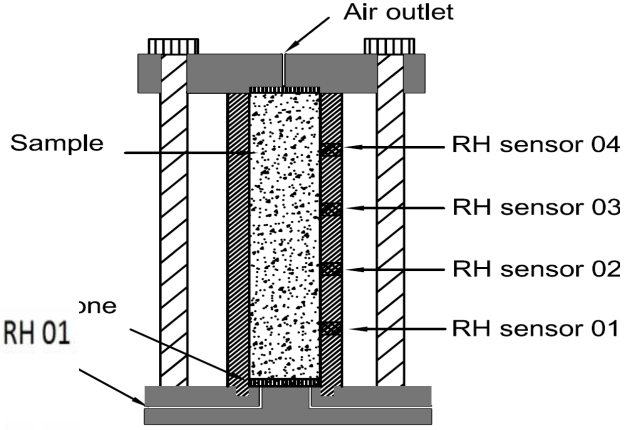
- Capillary pressure $p_c = \hat{p}_g - p_w$
- Entries:

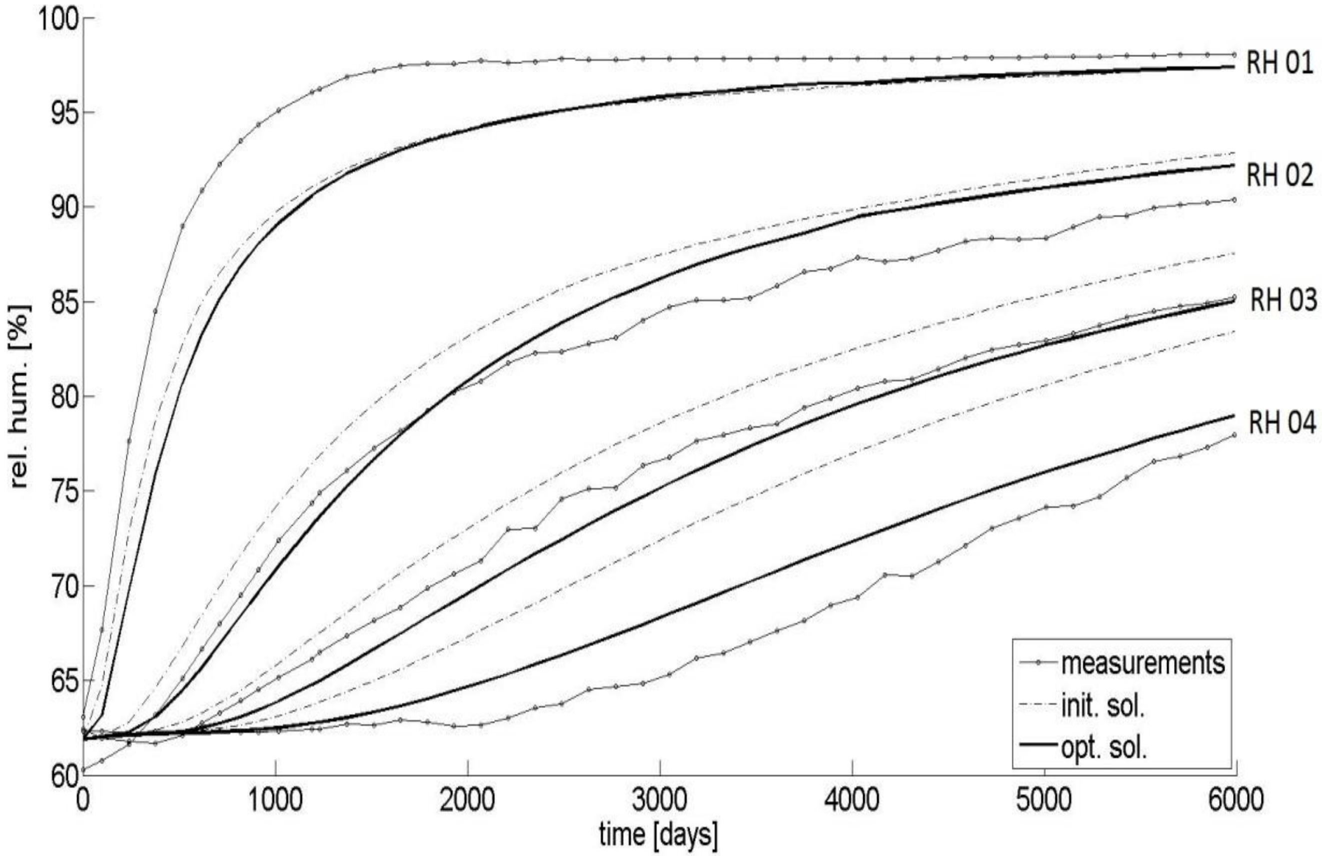
$$S_e = \begin{cases} (1 + |\alpha_{VG} \rho g p|^n)^{-m} = (1 + |\overline{\alpha_{VG}} p|^n)^{-(1-1/n)} & if \;\; p < 0, \\ 1 & if \;\; p \geq 0. \end{cases}$$

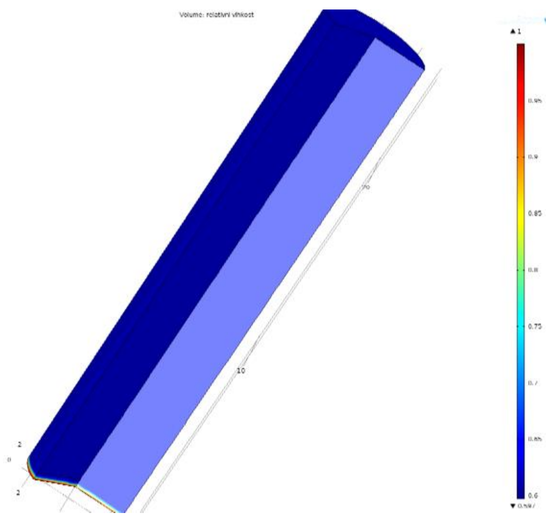
- Relative saturation $k_r(S) = S_e^k$

Results

Infiltration test

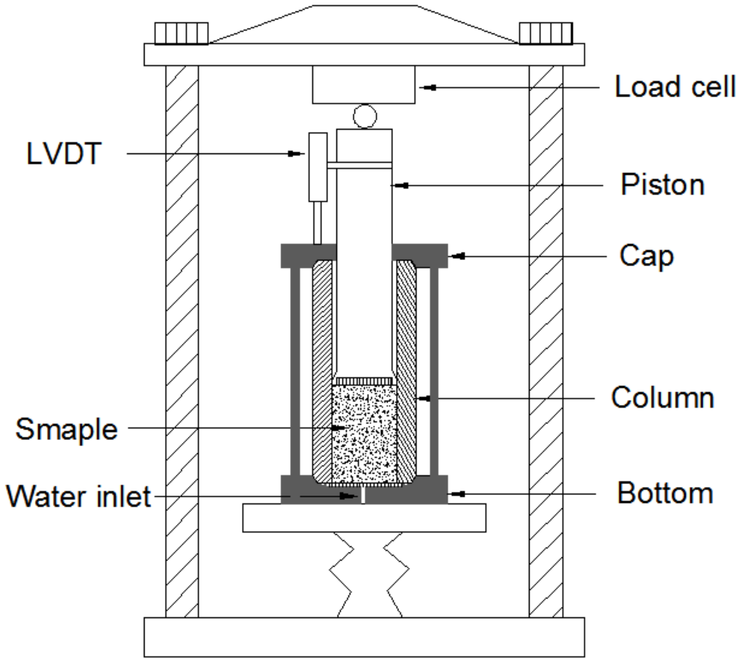


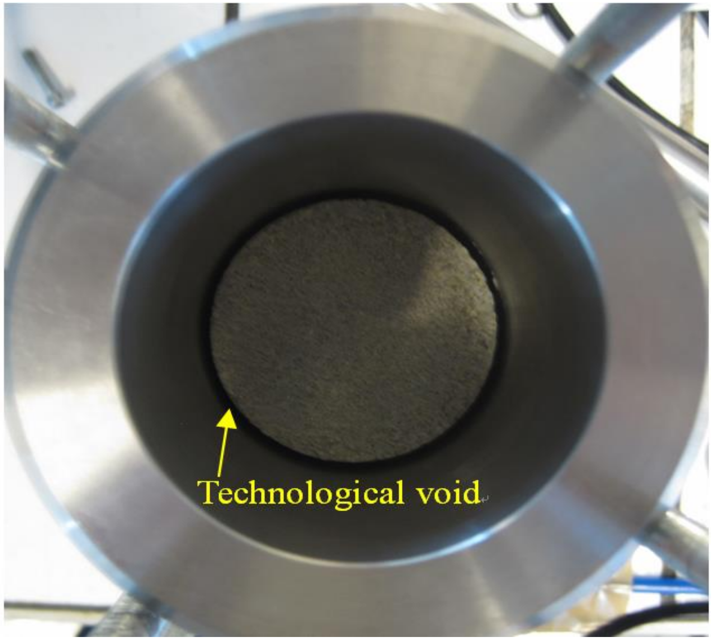




Experiments – Step 1

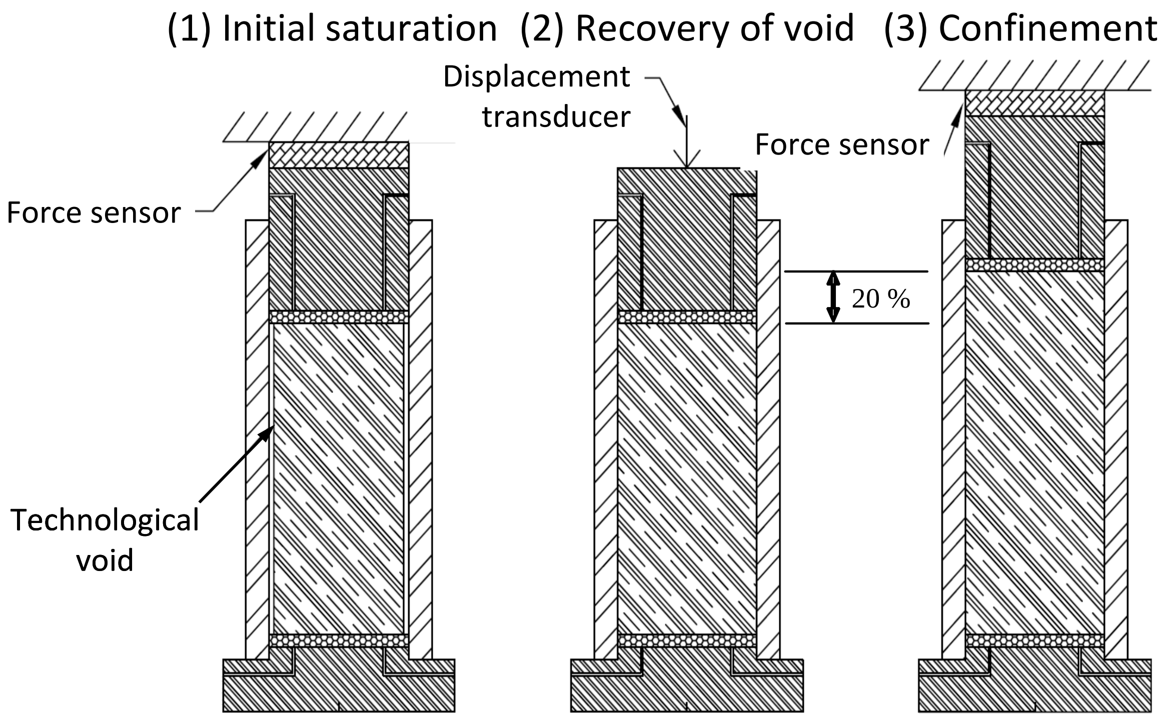
Similar to previous Step 0 - modelling of saturation process in bentonite MX-80, but under **unconstrained volume condition, HM !**



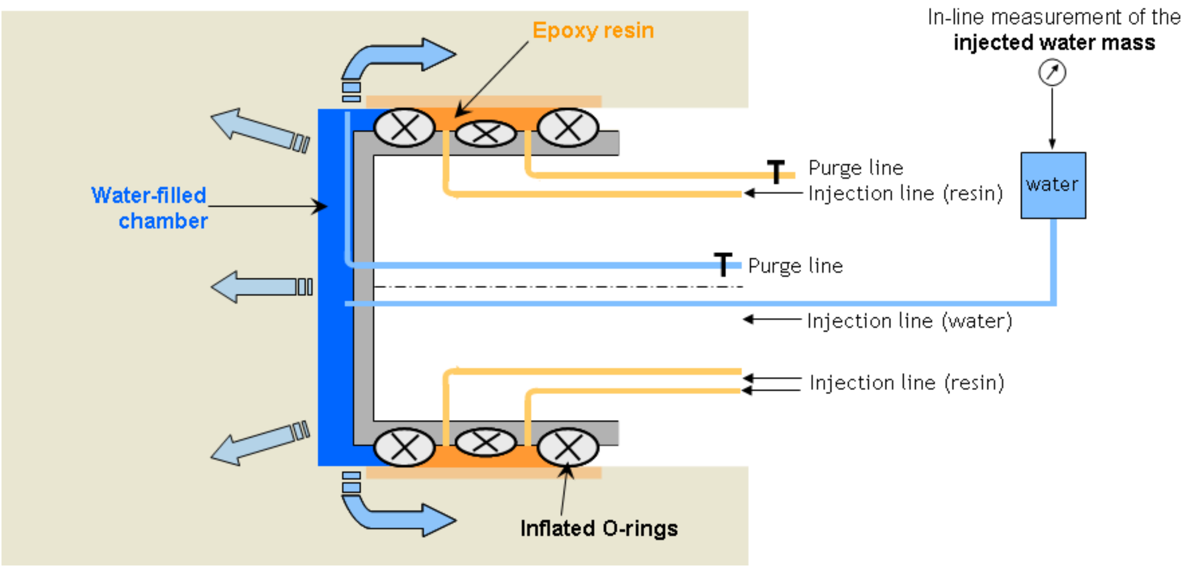


Experiments – Step 1

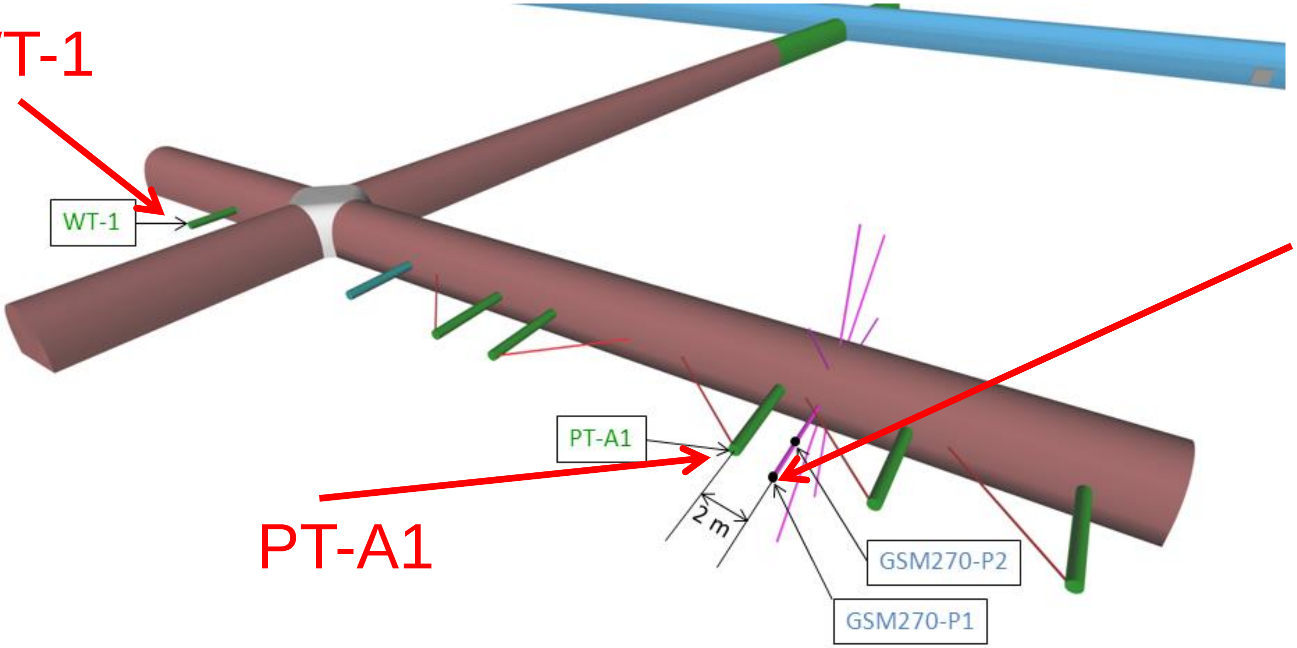
- Similar to previous Step 0 - modelling of saturation process in bentonite MX-80, but under **unconstant volume condition.**



In situ
WT1 test
PT-A1 test



WT-1



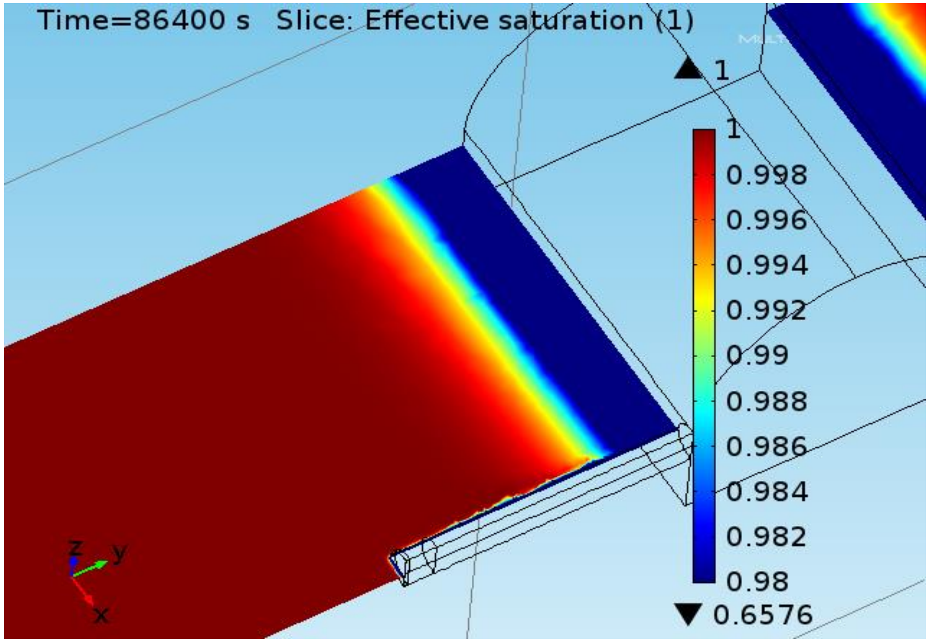
pore pressure measurement

PT-A1

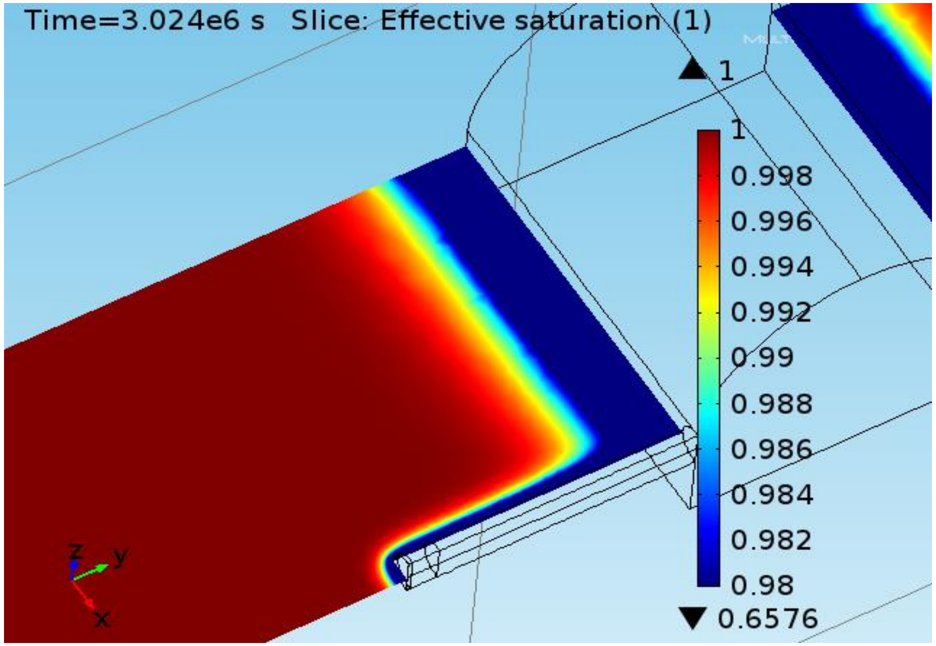
Results

3D model of the SEALEX WT-1 experiment

Effective saturation in rock 1 day and 35 days after borehole opening, pressure on the borehole wall p=-25 MPa.

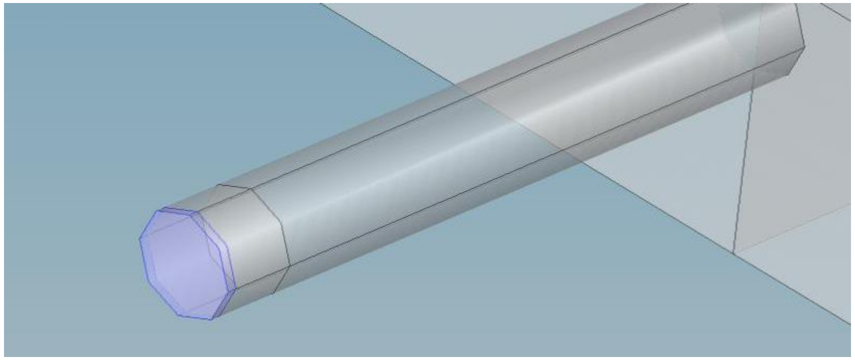


1 day after opening



35 days after opening [Pa]

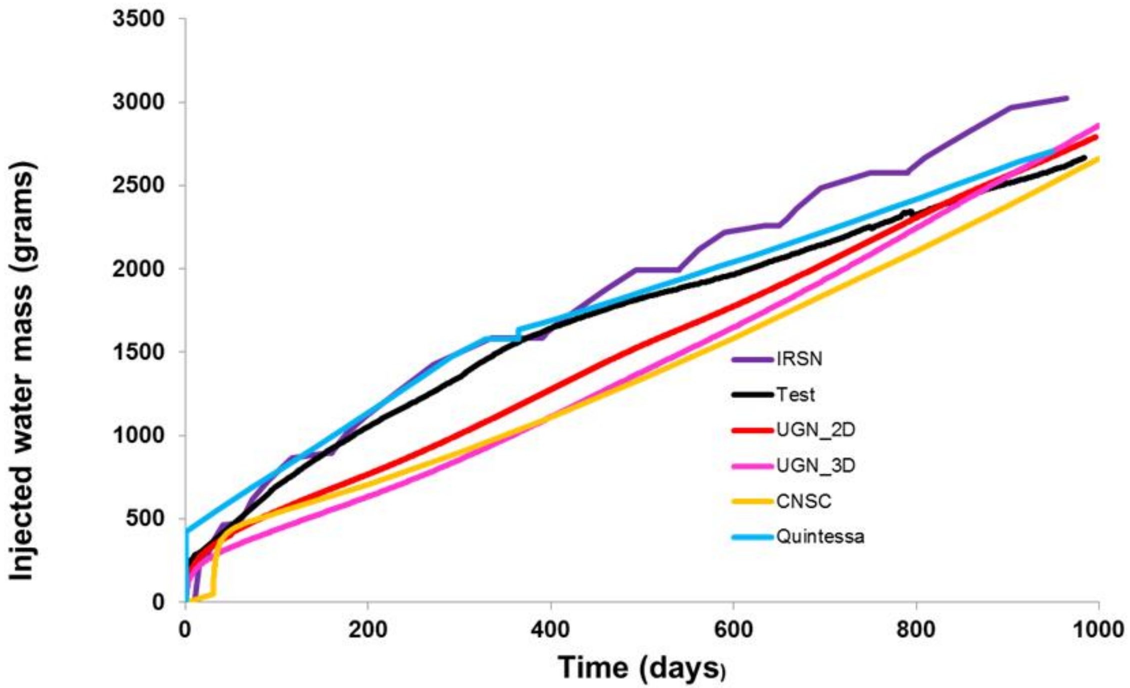
Experiments – Step 2 - results

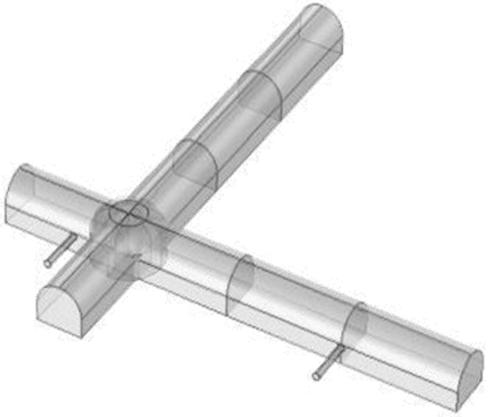


$$Q = \iint_A \vec{v} \cdot \mathrm{d}\vec{A}$$

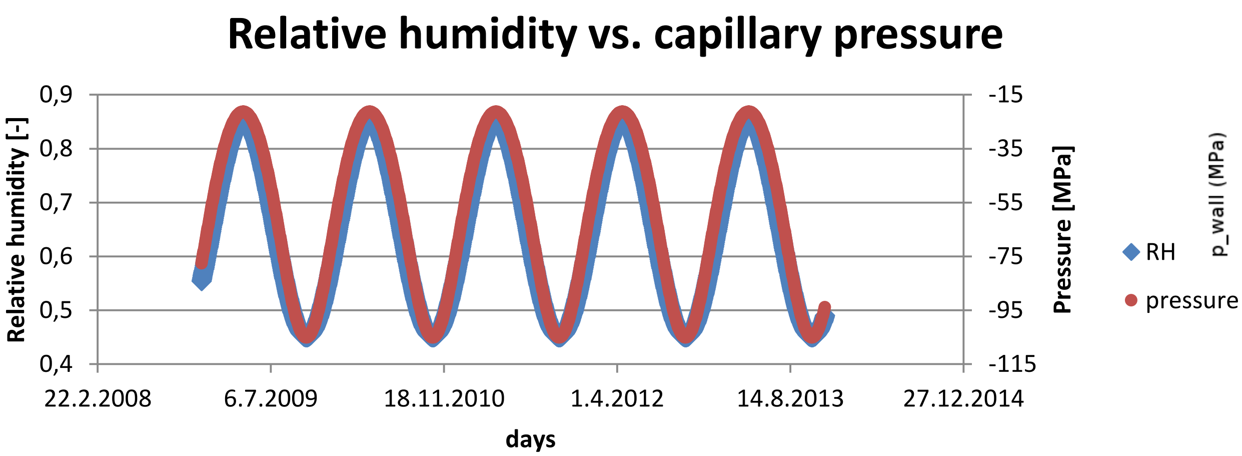
$\vec{v}$ - flow velocity

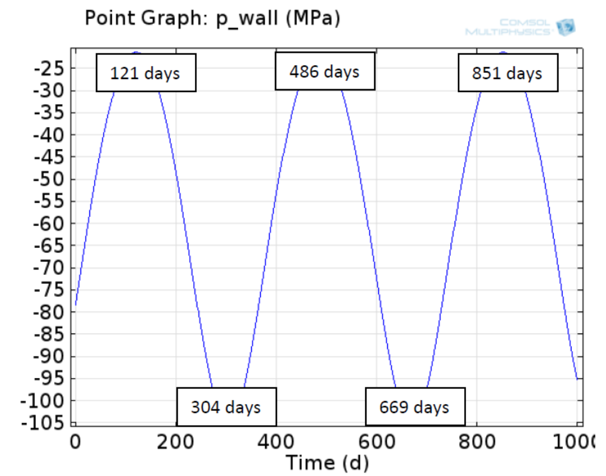
$\vec{A}$ - cross-sectional vector area/surface

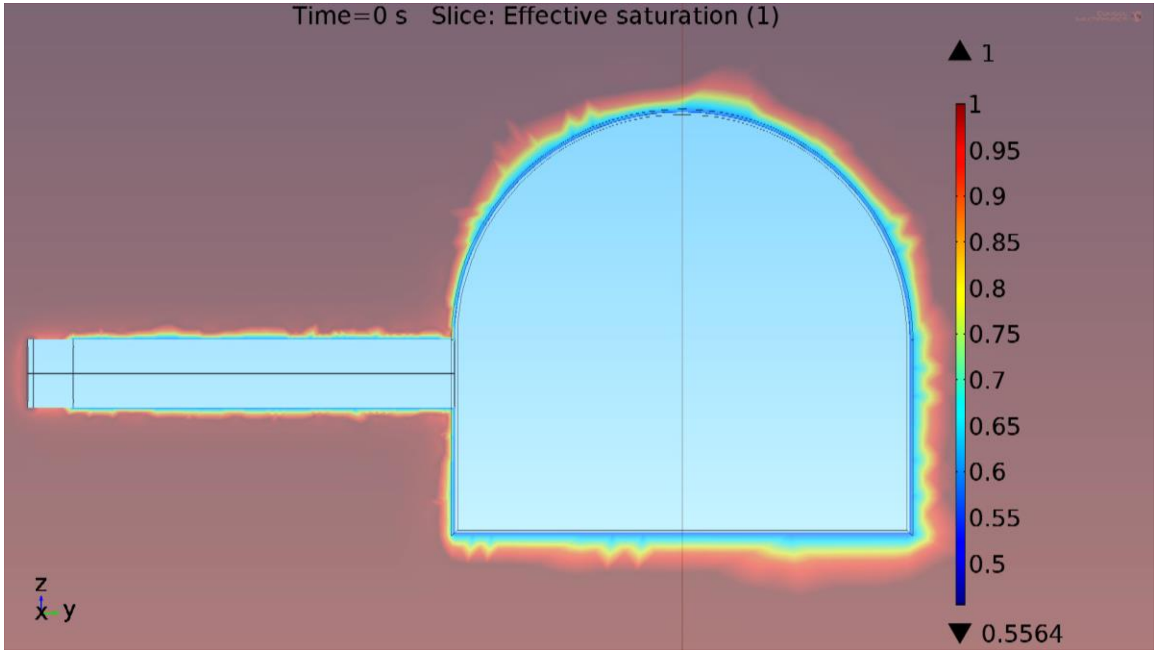


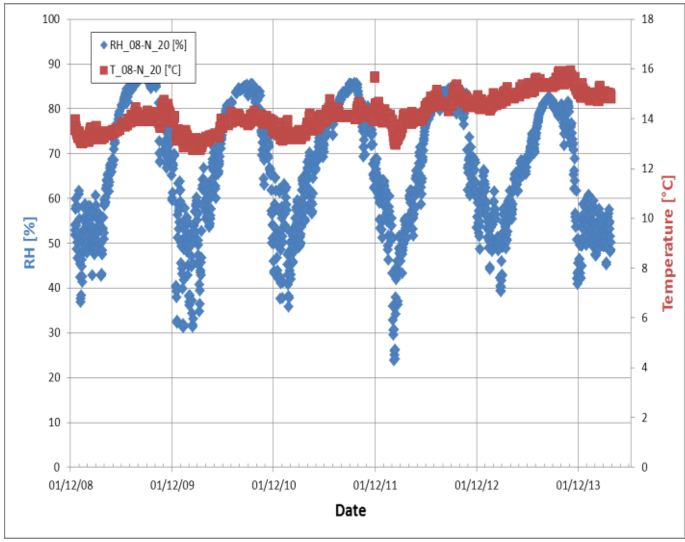


Results – boundary conditions





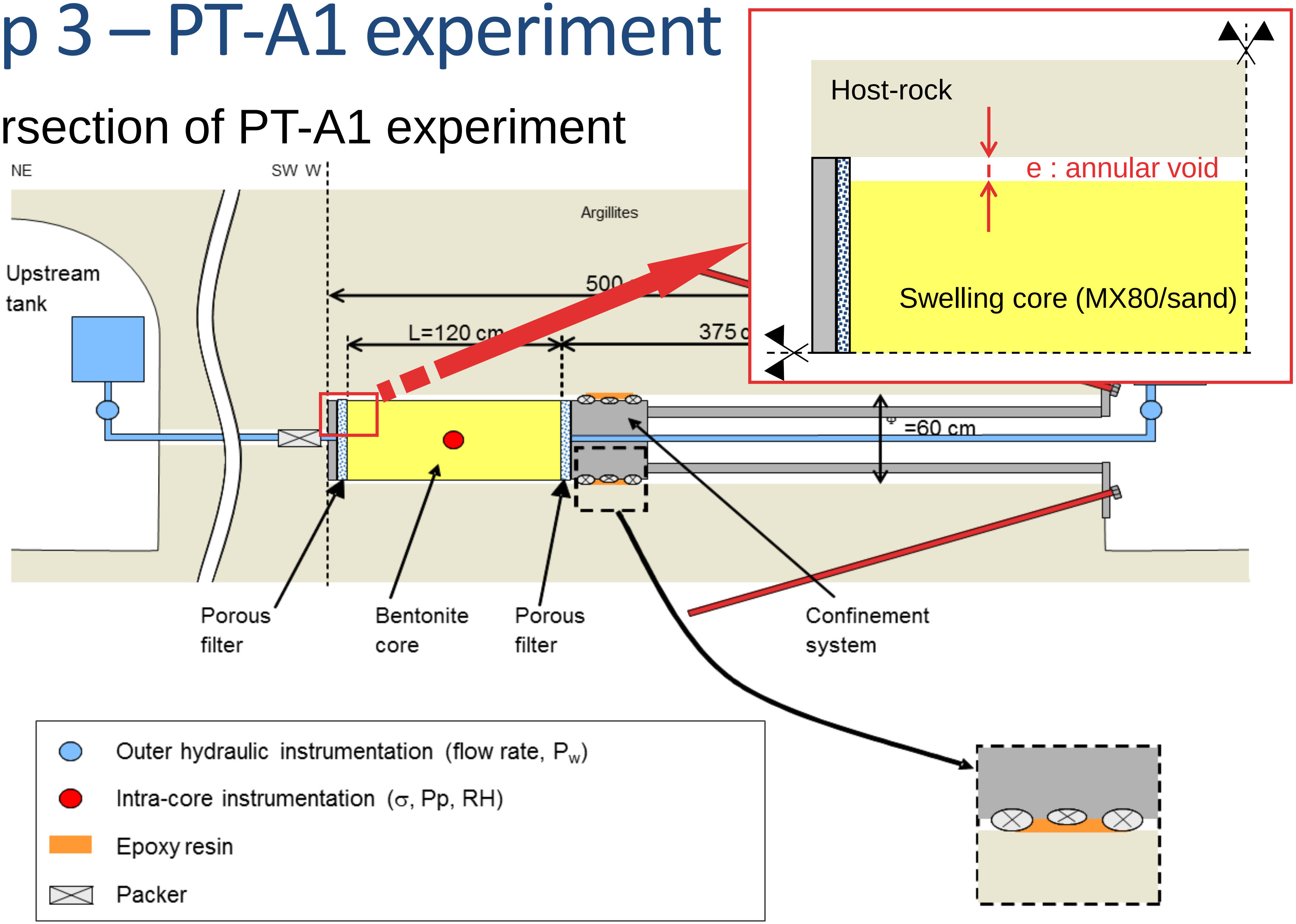




Effective saturation during year seasons

Step 3 – PT-A1 experiment

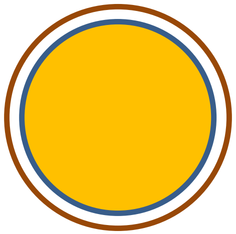
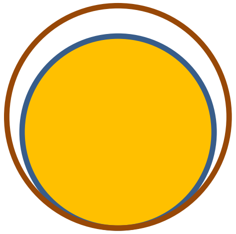
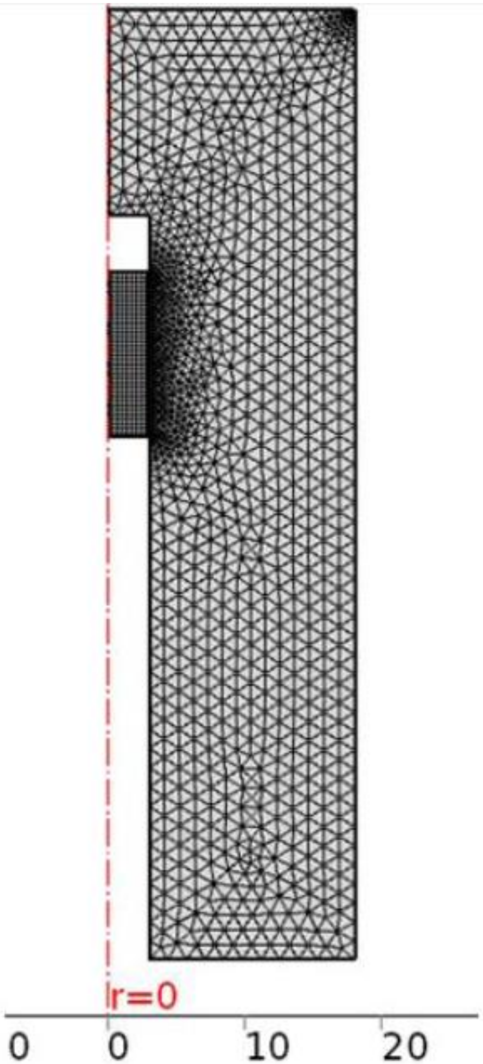
Intersection of PT-A1 experiment

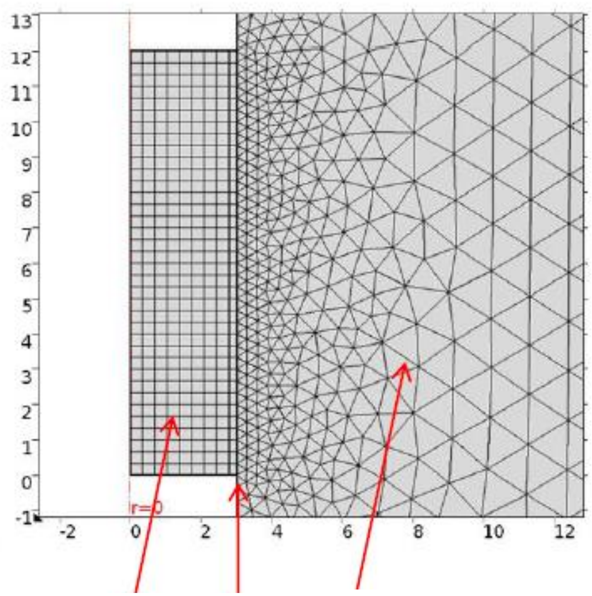


Sketch of the experiment

Axisymmetric model

Model aiming at formulation of considered processes not at obtaining best coincidence with measurement,

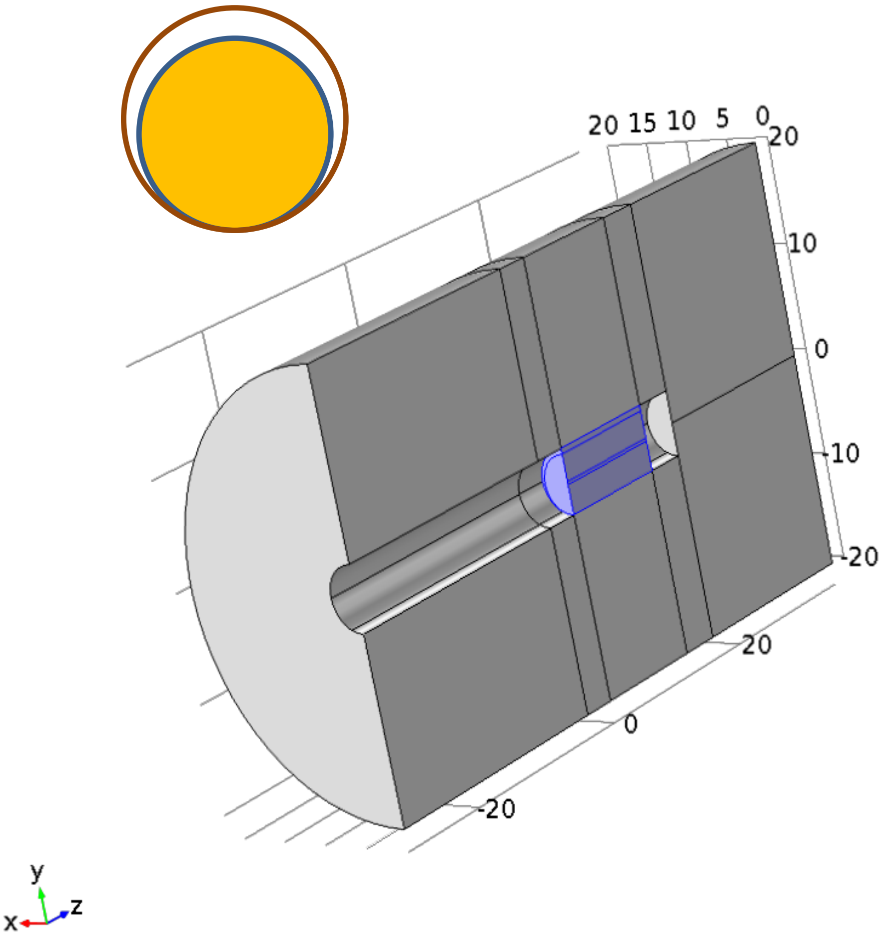




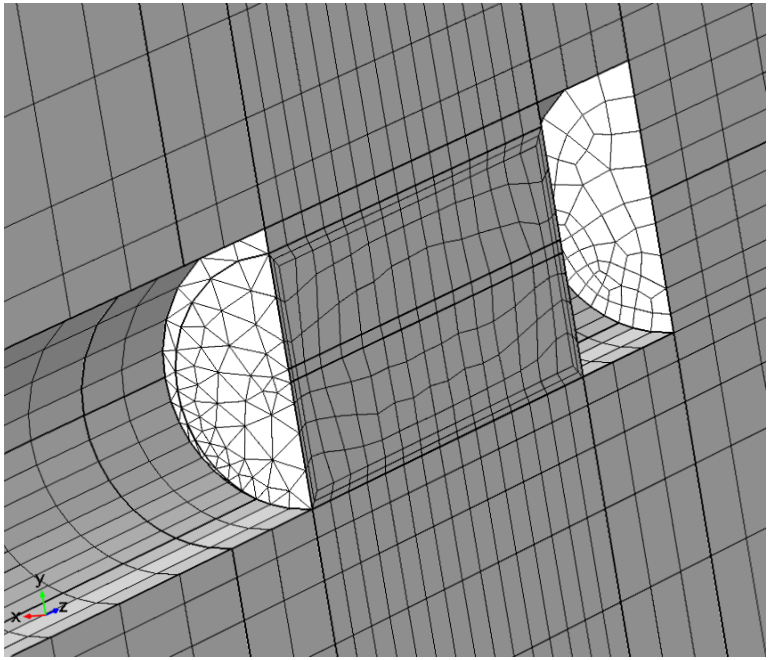


B **G**

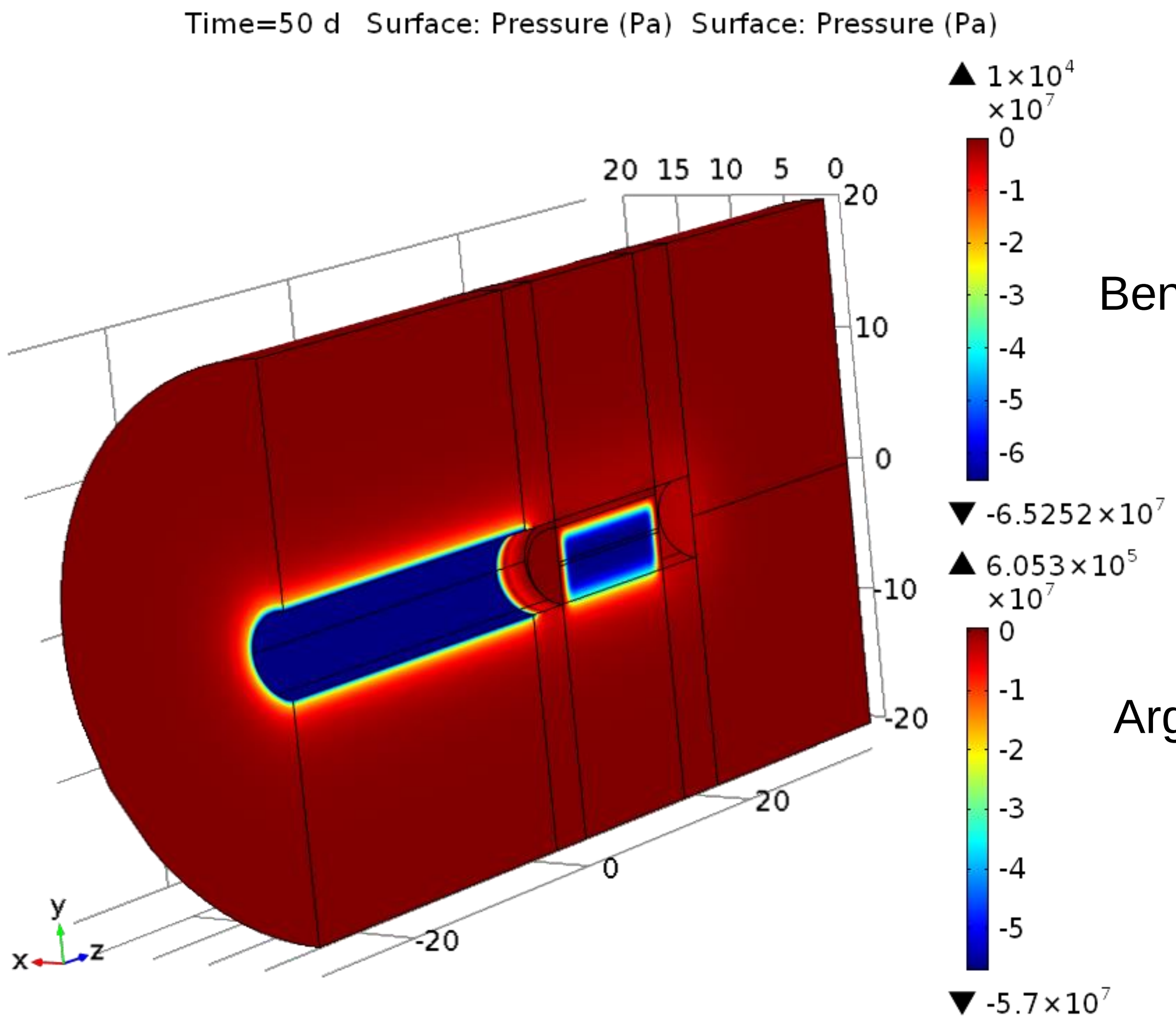
A= Argillite
B= Bentonite mixture core
G= Gap, which is gradually behaving as a bentonite

3D model with **nonsymmetric gap** and with **variable retention curve** depending on dry density





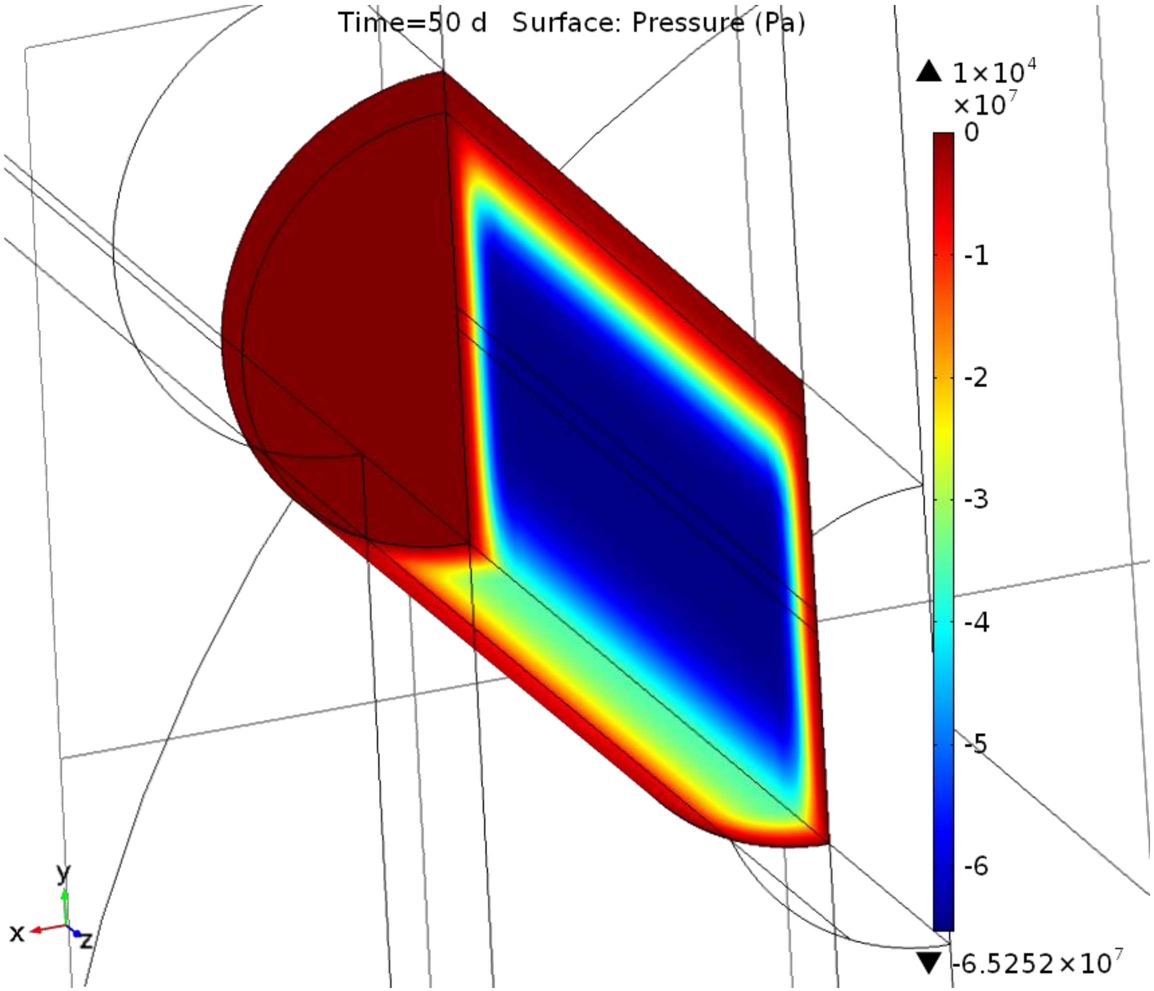
Pressure (suction) 50 days



Bentonite scale

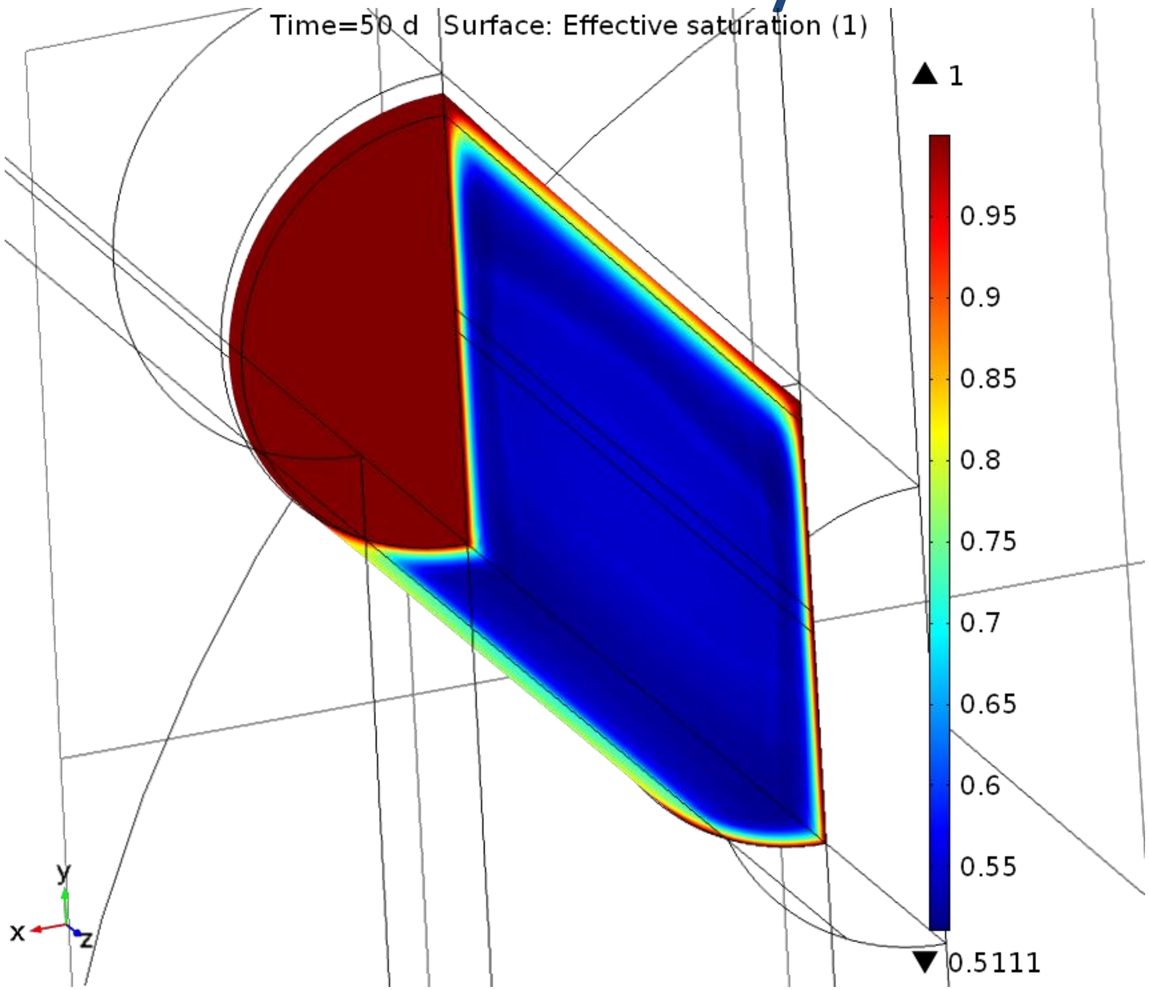
Argillite scale

Pressure (suction) 50 days



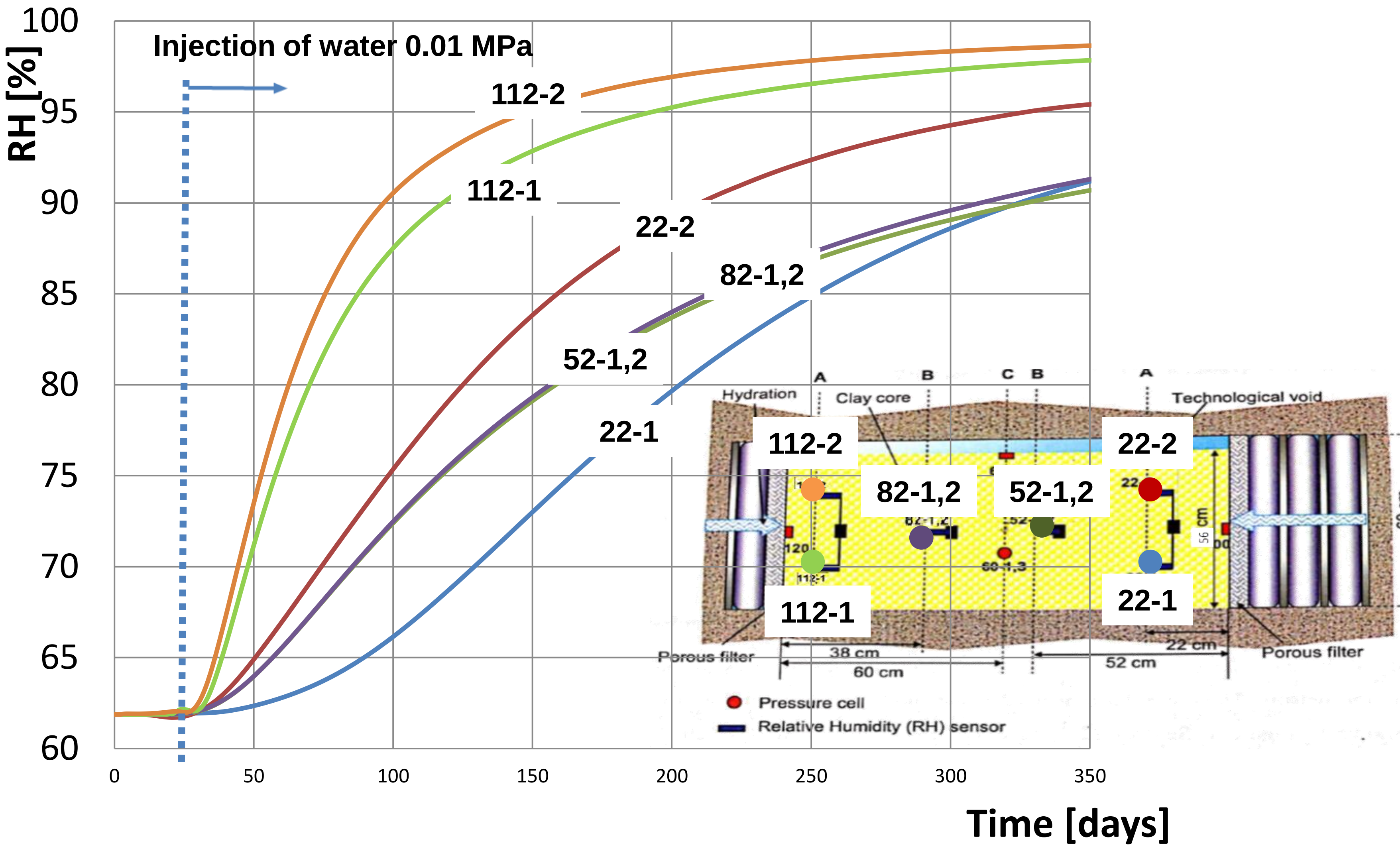
Suction decreasing, saturation depending also on pore size can be increasing/decreasing

Effective saturation 50 days



Note: minimal value of saturation is Se=0.51, which is below the initial state Se=0.57 for ρ_{dd}=1.94 Mg/m3. Seems to be due faster swelling expansion than saturation.

Relative humidity - computations

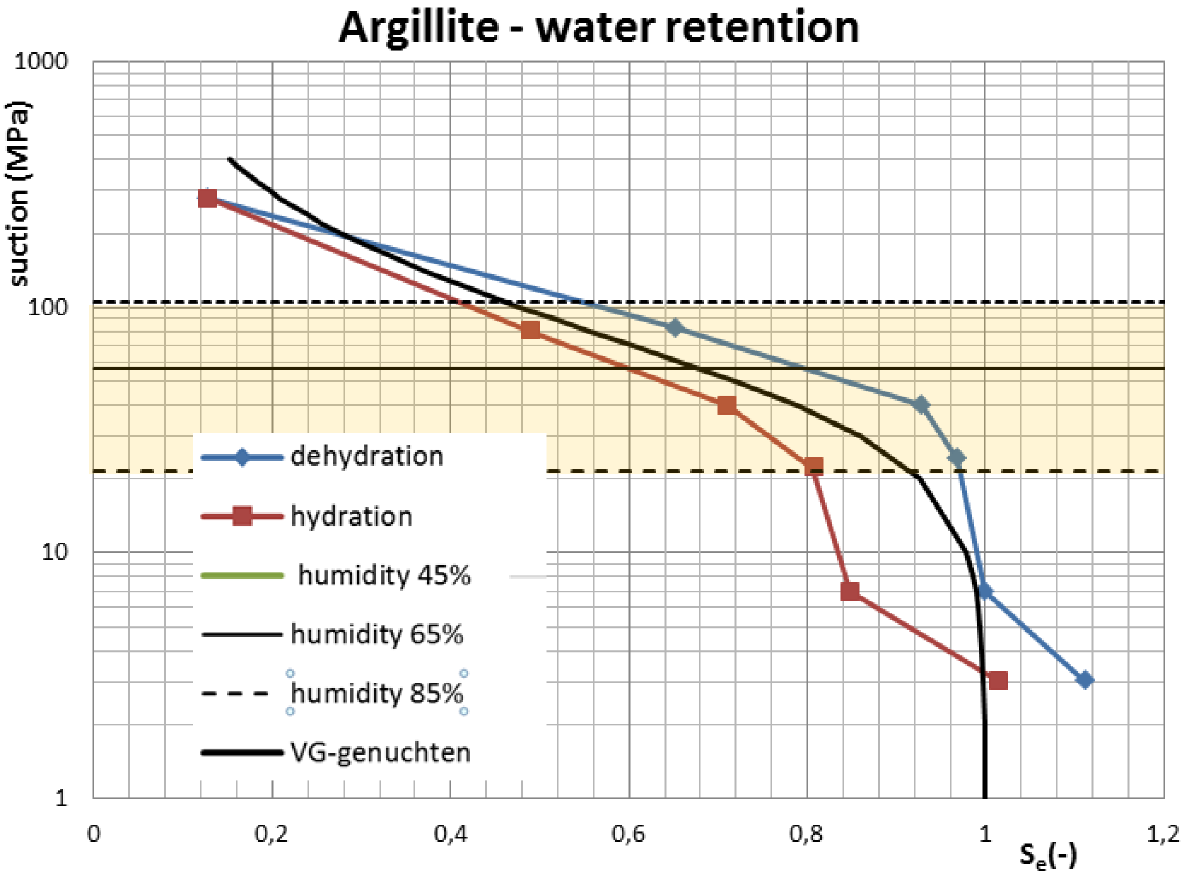


Thank you for your attention

Questions?

Considered processes

Water retention curve



provided data for hydratation/ dehydratation regimes

approximation by common Van Genuchten curve

not hysteresis

The marked layer corresponds to humidity 45-85% in the gallery

Argillite - elasticity with effective stress

$$-\nabla \cdot \sigma = f_s$$
$$\sigma = \sigma' - \alpha_B p I_\sigma$$
$$\sigma' = C : \varepsilon(u)$$

saturated flow

$$-\nabla \cdot \sigma = f_s$$
$$\sigma = \sigma' - \alpha_B \chi(S) p I_\sigma$$
$$\sigma' = C : \varepsilon(u)$$

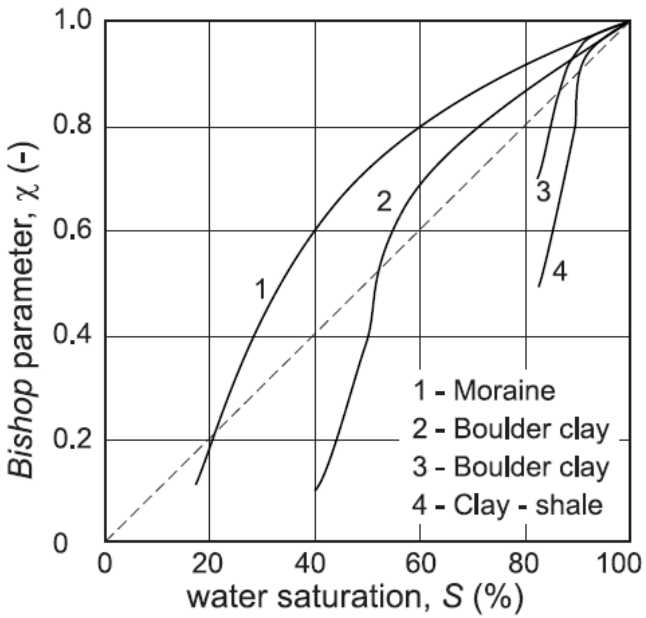
unsaturated flow

Biot-Willis constant $\alpha_B = 0.75$

Bishop function $\chi(S) = S$

C anisotropic linear elasticity

STEP 3 – now only Hydro

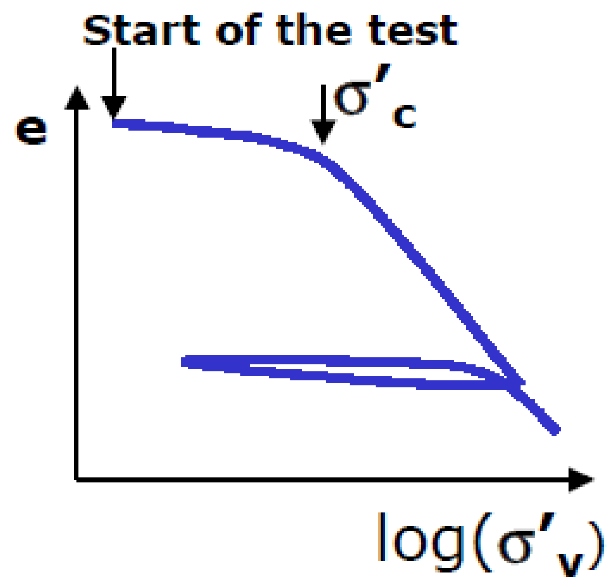


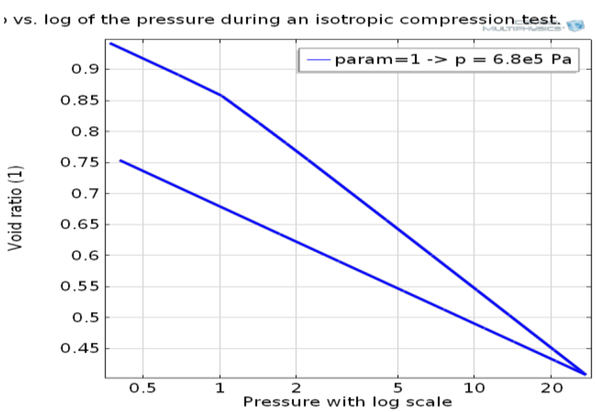
Bentonite – nonlinear elasticity

$$\sigma_v = -\frac{E(1-\nu)}{(1+\nu)(1-2\nu)}\varepsilon_v$$

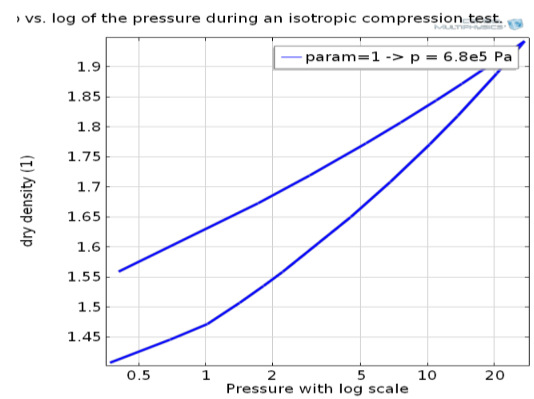
$$e = e_0 + \varepsilon_v(1+e_0),$$

$$E = E(e) = A \cdot 10^{B \cdot e}$$





$$e = \frac{\rho_s}{\rho_d} - 1 \Rightarrow$$



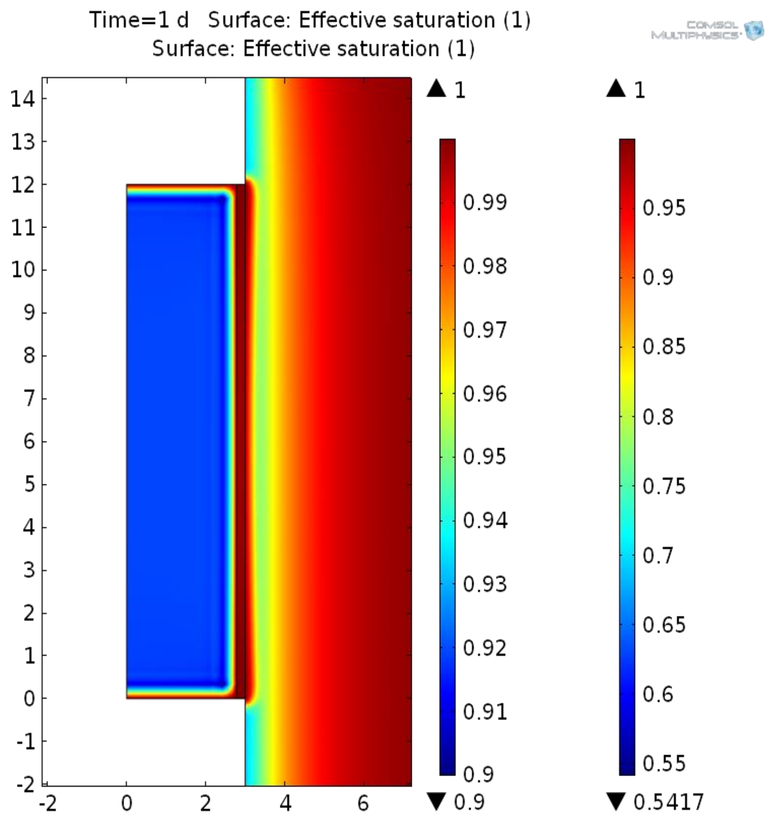
Bentonite – effective stress and pore space change

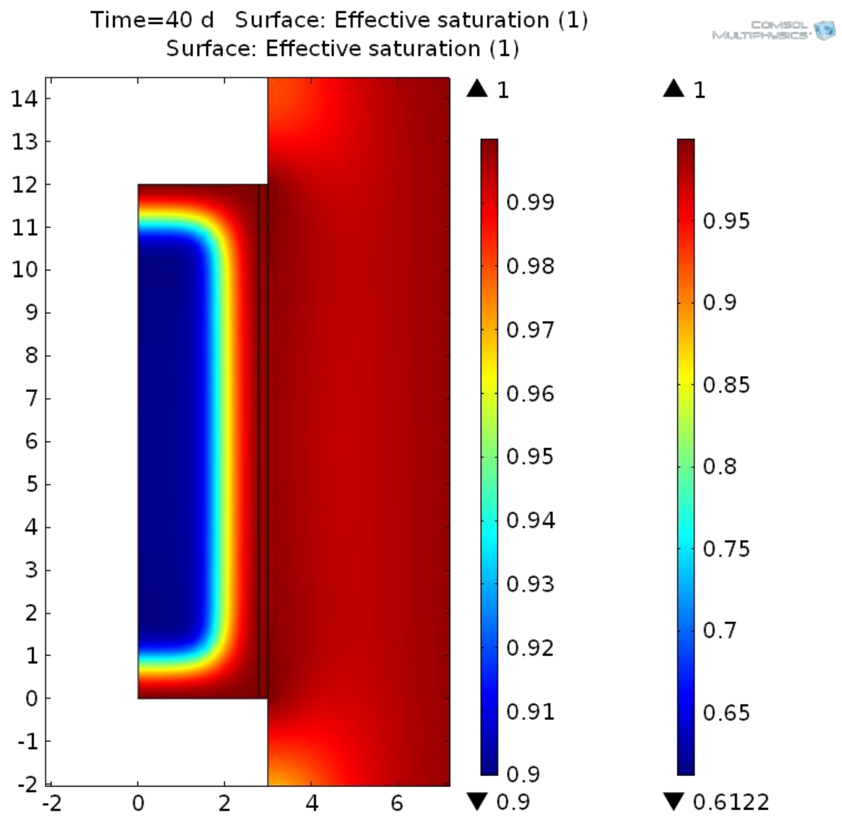
$$\sigma = \sigma' - \alpha_{BW}\chi(p) \cdot I, \qquad \sigma' = C : \varepsilon$$

$$\chi(p) = \max\{p_w, p_a\} \sim \begin{cases} p_w & p_w > 0, \\ 0 & \text{otherwise.} \end{cases}$$

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial t}\left(\frac{\phi_0 + tr(\varepsilon)}{1 + tr(\varepsilon)}\right) = \frac{\partial\left(\mathrm{tr}(\varepsilon)\right)}{\partial t}\frac{(1 - \phi_0)}{\left(1 + tr(\varepsilon)\right)^2}.$$

Evolution of the saturation – 1 and 40 days





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