Direct measurement of hysteretic water content in porous media using X-ray absorption

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Motivation

An alternative method to measure water content in porous media is presented. X-ray absorption provides direct information on water distribution with high resolution in time and space. We applied this technique on a column of sintered glass during imbibition and drainage to explore

- the hysteresis of the water characteristic
- the dynamics of water close to saturation

We compare the results to simulations using Richards Equation to investigate

- the possibility of modeling these dynamics using classical concepts

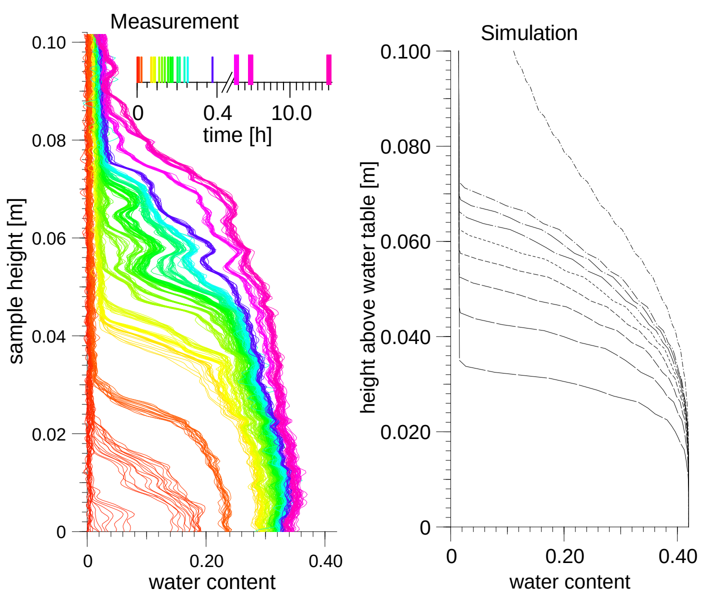
Results and conclusions

- the sintered glass medium shows huge hysteresis of the water characteristic
- measurements show a fast infiltration of water followed by a slow process towards full saturation
- the simulation of imbibition can not reproduce the observed dynamics since Richards Equation neglects the relevant multi-phase processes
- simulations of drainage are in reasonable agreement with measurements

Dynamics of water content

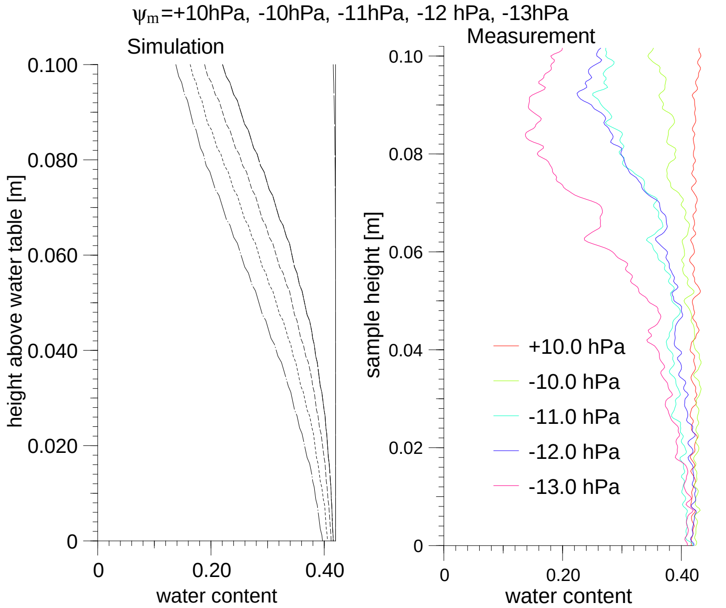
Imbibition

At t=0 the sample was connected to free water at lower boundary

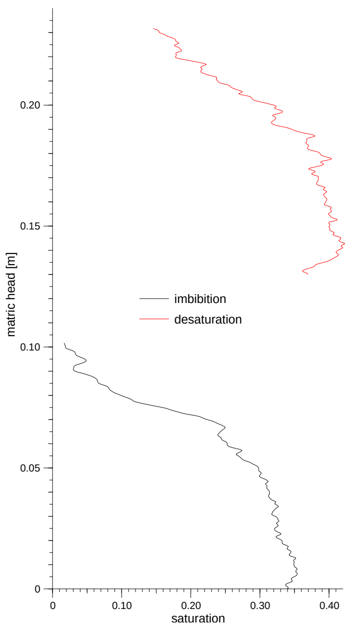


Drainage

Stationary states for decreasing water potential at lower boundary of ψ_m=+10hPa, -10hPa, -11hPa, -12 hPa, -13hPa



Hysteresis



Materials

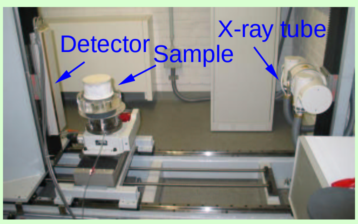
Data shown on this poster were obtained using a sintered borosilicate glass column with h=95mm height and 160mm in diameter. The porosity is Φ=42% with pore radii between 160μm and 250μm. The sample was coated with silicon to prevent air entries through the boundary surface. The X-ray absorption coefficients for the two materials are $\mu_{\text{glass}} = 0.033\frac{1}{\text{mm}}$ and $\mu_{\text{H}_2\text{O}} = 0.019\frac{1}{\text{mm}}$ at a photon energy of 100keV.

Method and experimental setup

We used a X-ray system as shown in the picture beside:

- medical tube at 141kV and 5.0mA
- ccd linesensor: 1280 square pixels of size 0.4mm
- sample thickness passed by the beam: d=155mm
- vertical resolution is given by the pixel size of the detector
- water potential at lower boundary was adjusted

Water content profiles within a vertical sheet of thickness 0.4mm were measured at frequencies up to 1s^{-1} during imbibition.



The intensity $I(\Theta,d)$ at the detector is discribed by

$$I(\Theta,d) = I_0 e^{-\mu^*(\Theta)\cdot d}$$

with an absorption coefficient that depends on water saturation Θ

$$\mu^*(\Theta) = (1-\Phi)\cdot\mu_{\text{glass}} + \Theta\cdot\mu_{\text{H}_2\text{O}}$$

To get information about the water saturation we subtract the values measured with the completely dry column from values of the wetted column. Then the measured values were scaled so that the results for the completley saturated sample matches the measured porosity of 42%.