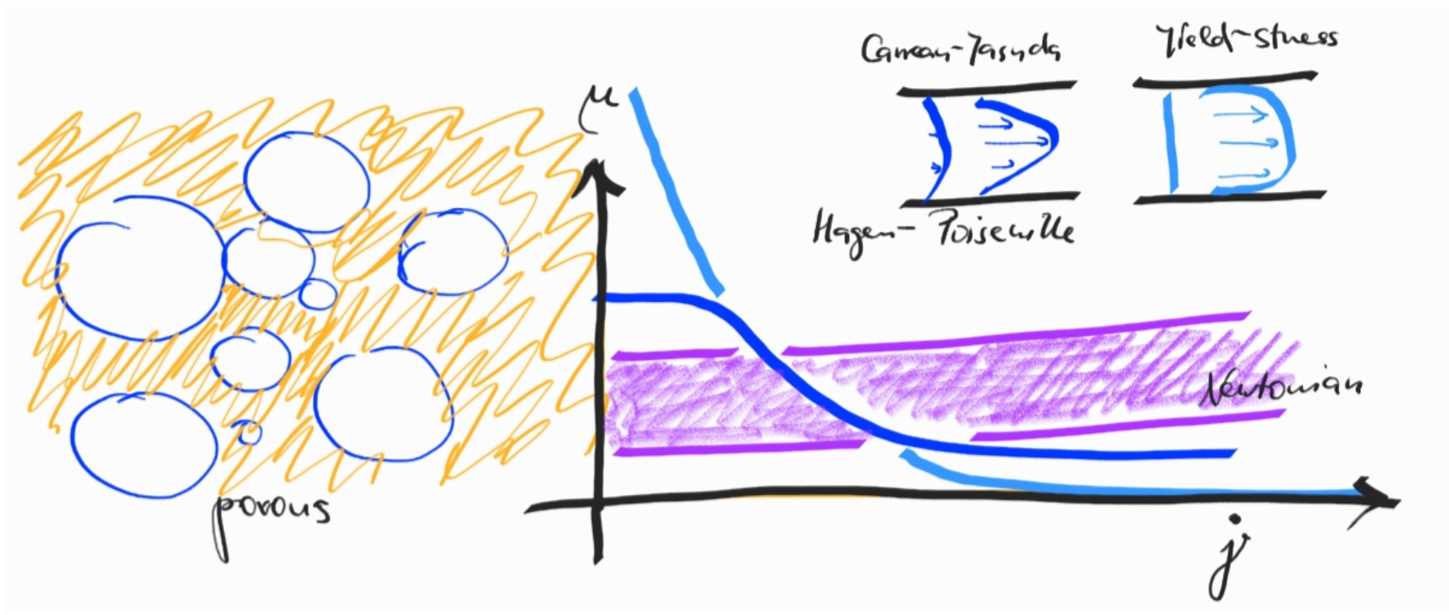

Measuring the pore size distribution of a soil sample during the saturated triaxial compression using non-Newtonian fluids

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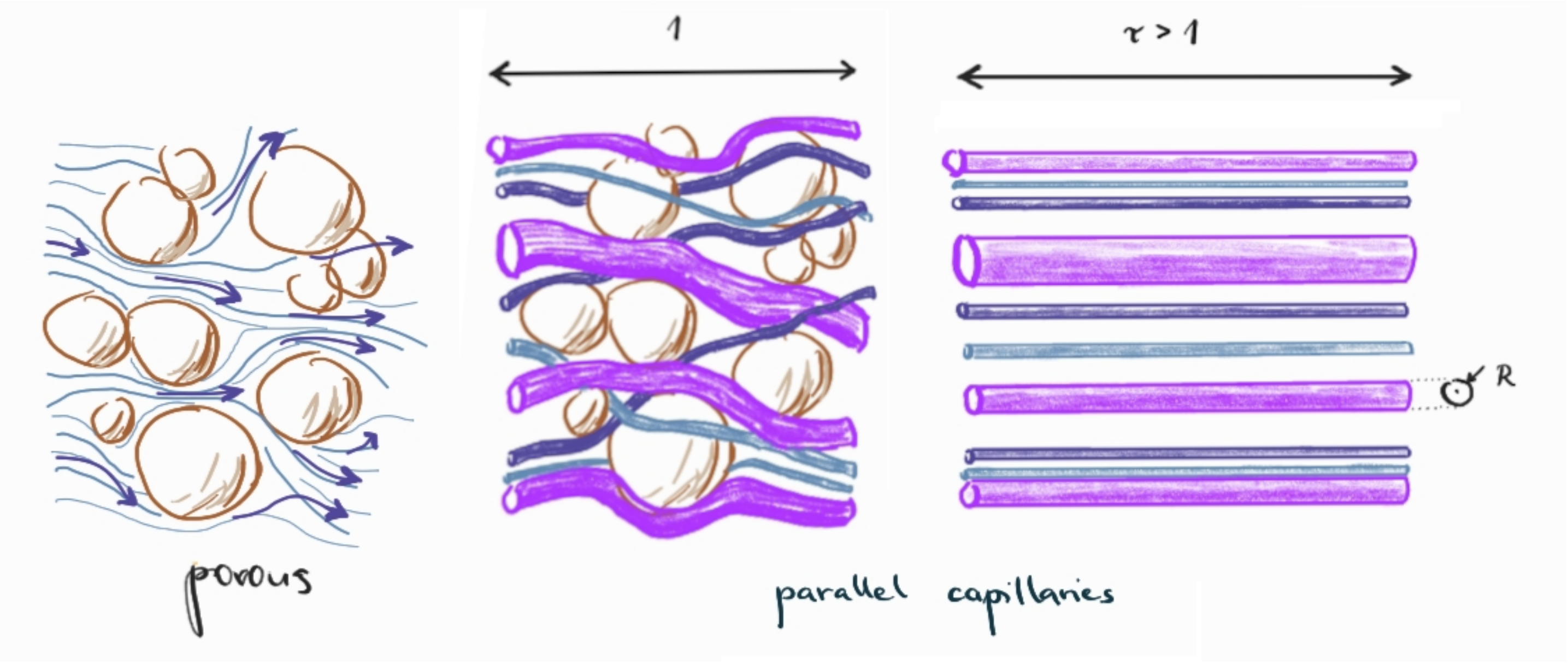
Framework: Effective pore-size distribution

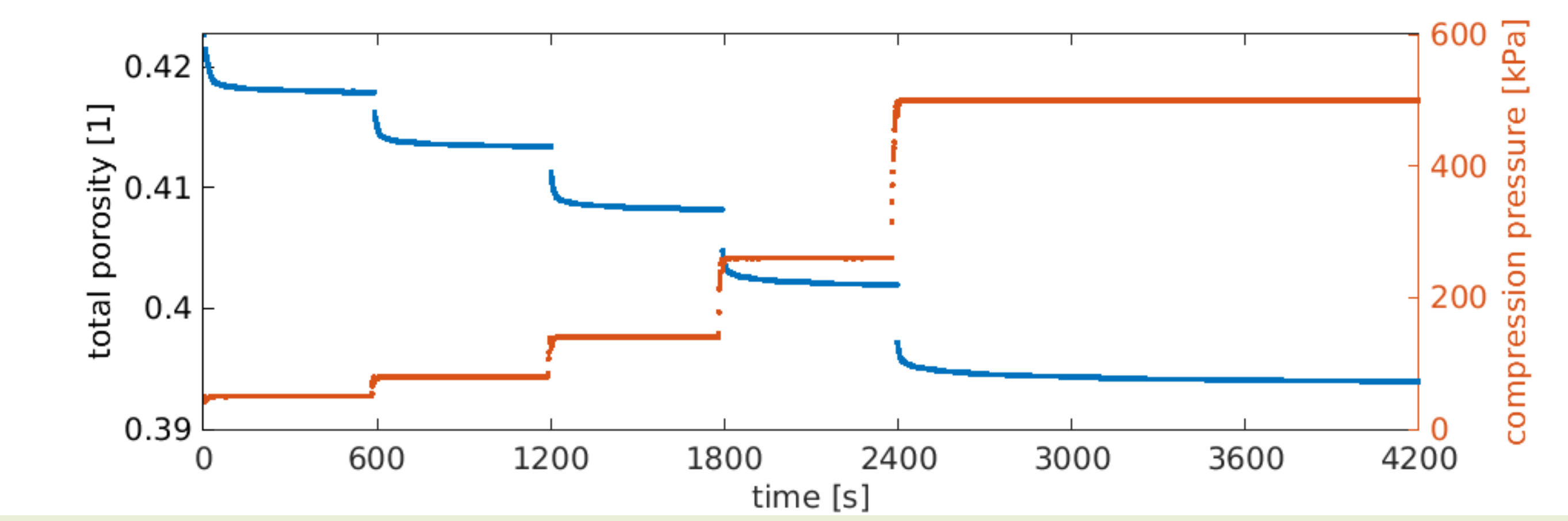
The geometry of the pore space determines many properties of soils, including hydraulic, transport, and other characteristics. One of its key features is the pore-size distribution (PSD), the representation of different pore sizes. In particular, the effective PSD is defined by the capillary bundle model of the medium:



The effective PSD is defined by the saturated hydraulic conductivity of the pores: the flow is simplified as if occurring through parallel tortuous (cylindrical) capillaries of different radii.

Aim: PSD evolution during soil compaction

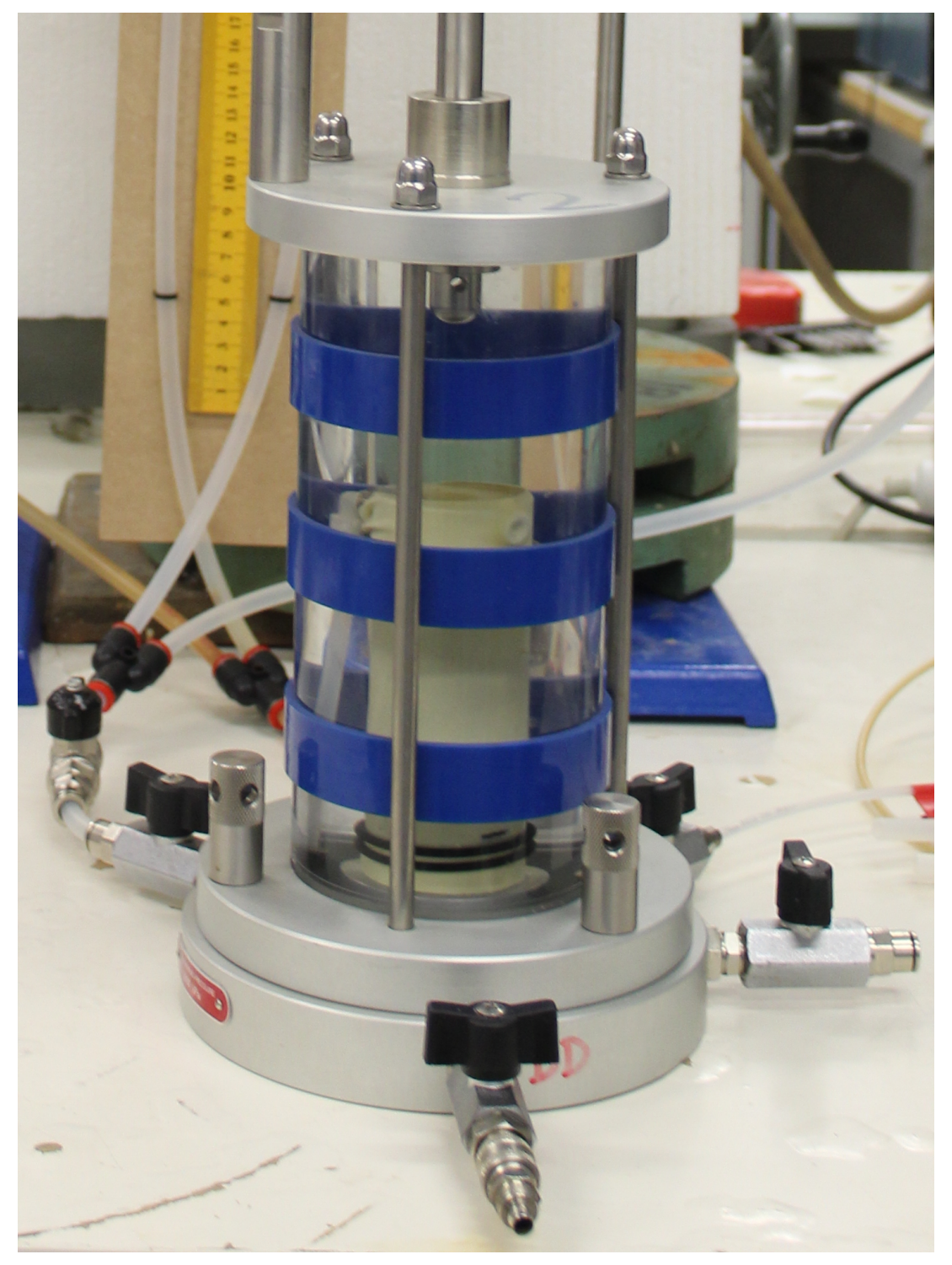
We are designing a low-cost laboratory experiment to track changes in the effective PSD as the soil sample undergoes triaxial compaction:



While it is easy to measure how the total porosity shrinks in the compacted soil, reducing the pores sizes in general, it is costly and demanding to establish the variation of pores of different sizes experimentally (e.g. using μCT).

As a natural loose material, we use *Zbraslav sand* which is a sandy soil with a high percentage of coarse sand. Moreover, for the first experiments, the particles smaller than 0.1 mm were removed.

E1. Triaxial compression

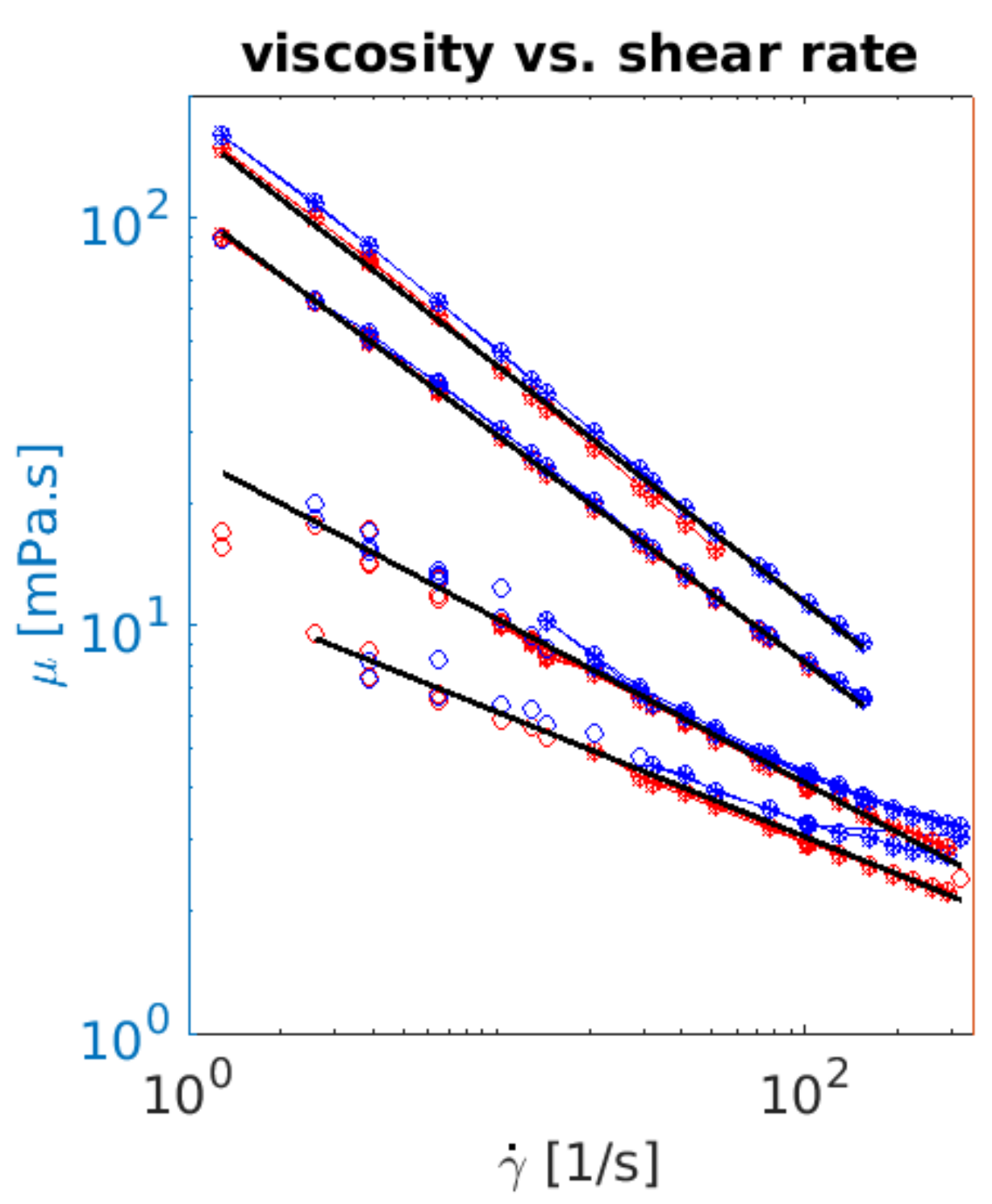


A small soil sample ($d = 38$ mm, $h = 72$ mm cylinder) is fitted in rubber membrane and installed into the standard triaxial pressure cell permeameter (see fig.), where it is exposed to confining pressure generated in the cell.

For the permeability measurement, the sample bases are connected to the inlet and outlet tubes through a set of plastic and metal meshes of different mesh sizes, ensuring both the permeability for fluid and the barrier for small sand particles.

The cell is to be pressurized in subsequent steps in order to apply from 2 m up to 50 m of the effective pressure head.

E2. Shear-thinning fluids



Aqueous solutions of xanthan gum of different concentrations (0.3, 0.4, 0.6 and 0.8 g/l) are used for the permeability experiments.

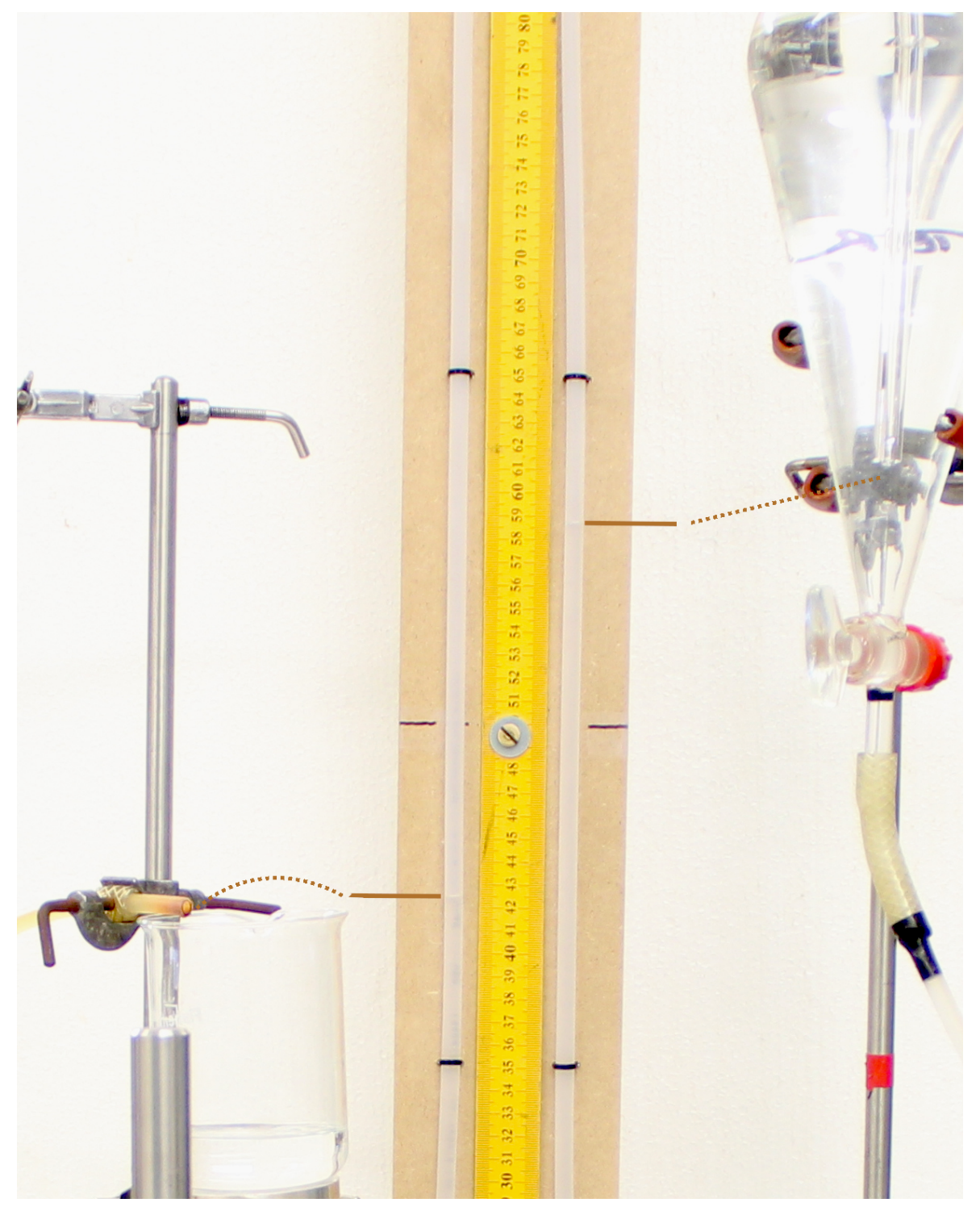
Their viscosity (measured on low-viscosity rotational viscometer) at shear-rates $\dot{\gamma}$ of approx. 1–250 s^{-1} follow the power-law (see fig.):

$$\mu \sim \dot{\gamma}^n \qquad \text{with} \qquad 0 < n < 1.$$

Their laminar volumetric flux through a simple cylindrical capillary of radius R, when subject to the effective pressure gradient ∇P, is then:

$$Q \sim R^{2+\beta}\,\nabla P^{1+\beta} \qquad \text{with} \qquad \beta = \tfrac{1}{n} - 1 > 0.$$

E3. Permeability measurement



Standard permeability measurements are performed for the above set of shear-thinning fluids.

Constant hydraulic gradients are achieved simply by keeping the reservoir (Mariotte's bottle) level above the outlet level. For accurete hydraulic heads reading, two burettes are positioned as close as possible to the triaxial cell. The steady discharge value is measured using analytical weights.

Note that only small hydraulic gradients (up to 2 for initial experiments, up to 8 under compression) are applied, in order to keep the perturbation from the homogeneous effective stress below 5 %.

PSD inversion

The effective PSD is approximated using the ANA method, see [1, 2].

Briefly explained, the total flux v of fluids with different power-low index n is distributed differently among capillaries of different sizes. Formalizing by

$$v = \int_0^\infty q(R)\,\mathrm{d}W(R) = C(\mu_0, n)\nabla P^{1+\beta} \int_0^\infty R^{2+\beta}\,\mathrm{d}W(R),$$

an inverse problem is solved, approximating the cumulative PSD function $W(R)$ from known values of the latter integral.

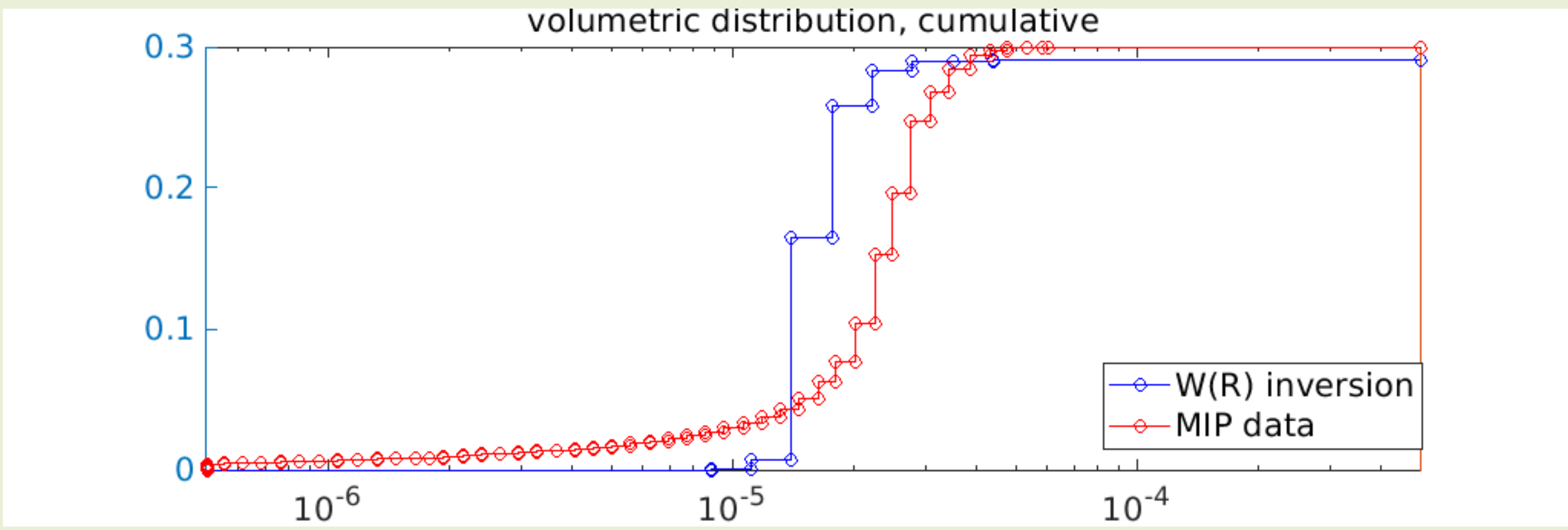


Illustration of the inversion for another sample, using water + 6 fluids.

[1] Majdi R. Abou Najm and Nabil M. Atallah.
Non-newtonian fluids in action: Revisiting hydraulic conductivity and pore size....
Vadose Zone Journal, 15(9):vzj2015.06.0092–vzj2015.06.0092.

[2] Scott C. Hauswirth, Majdi R. Abou Najm, and Cass T. Miller.
Characterization of the pore structure of porous media using non-newtonian fluids.
Water Resources Research, 55(8):7182–7195.

Results, Issues

Experiments are in progress... So far, the main issues are:

- Under the low hydraulic gradients, the permeability measurement is very slow for higher polymer concentrations.
- The fluid replacement in the pore space is also more demanding, due to fluids' non-Newtonian rheology.
- For low polymer concentrations, the accuracy of both the viscosity characterization and the PSD inversion is reduced.

By early assessment, the methodology may prove to:

- be limited to media with rather high permeability;
- or limited to higher effective pressures (so that higher hydraulic gradients are allowed);
- require quite accurate measurement of fluids with shear-thinning viscosities close to that of water.

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