**Assessment of two-phase constitutive relationships in water-air flow systems of mixed-wetting granular porous media**

*Physical background*

Pressure and saturation of fluids are the key variables in the analysis of multiphase flow in porous media. Furthermore, secondary variables such as relative permeabilities (kr) and capillary pressures (Pc), which are functions of fluid saturations (S), are needed for the simulation of displacement processes in porous media. In numerical simulations, experimentally determined constitutive relationships of two-phase systems are often used as input parameters to numerically predict the relative permeabilities required in three-phase flow simulators (Schäfer et al., 2020).

Pore space structure together with wettability significantly influence the multiphase flow properties of porous media. For flow of immiscible fluids through porous media, capillarity has a dominant influence on relationships between fluid distribution and pore space properties. In a two-phase fluid system, numerous experiments show hysteresis in Pc-S relationships (Haines, 1930) but also for nonwetting fluids in kr-S relationships. In hydrosystem modeling and remediation of polluted soils and aquifers, but also in oil reservoir simulation, it is crucial to know in detail the characteristic of these curves.

*Gap of knowledge: effect of wettability of unconsolidated porous medium on Pc-S and kr-S*

Most reported data on hysteresis of Pc-S curves are for water-wet unconsolidated porous media, such as bead and sand packs (e.g. Pham et al., 2005). Only few experimental data are available to assess the influence of interfacial tension (IFT) of the fluid pair involved on the complete cycle of drainage-imbibition and two-phase kr-S data (e.g. Dury et al., 1998). Dury et al. (1998) reported capillary pressure-saturation curves that scaled according to the surface tension ratio. While the Pc-S curves showed considerable hysteresis between wetting and drying with respect to capillary pressure, no hysteresis was found in the hydraulic permeability curves with respect to saturation and all curves described a unique function of saturation. Contrary to hydraulic permeability, pneumatic permeability however showed significant hysteresis with respect to saturation.

To our knowledge, there are actually only very few experimental data available in the literature, which assess in detail and quality the effect of the change of wettability of unconsolidated porous media, from water-wet via intermediate wet to oil-wet, on two-phase Pc-S and kr-S data.

*Experimental setup and mixed wetting granular porous media*

Two experimental setups will be used to assess the influence of wettability on Pc-S and kr-S relationships in a water-air flow system.

- Column of aluminium (20 cm high, 3 cm inner diameter) equipped with water saturated membrane and 2 small tensiometers with pressure transducers. To quantify the relative hydraulic permeability as function of water saturation, the so-called steady-state (unit gradient) control method (Klute and Dirksen, 1986) will be used: a hanging water column is connected to the sand column outlet, and a continuous irrigation with a constant water flux is applied on the upper inlet section.
- Column composed of a water saturated ceramic porous cylinder (15 cm long, 3 cm inner diameter, 0.1 MPa air entry value) enclosed in a PVC mantle and equipped with a U tube water manometer connected to the inflow and outflow chambers of the column. To quantify the relative air permeability as function of water saturation and

retention (Pc-S) curve, both characteristics will be measured simultaneously using the setup of Fischer et al. (1996). It is based on a homogenous sand packing placed in a ceramic cylinder with water-saturated walls to allow drainage or imbibition.

The experiments will be conducted in replicates using a uniform medium sand with different wettabilities ranging from water-wetting sand, through intermediate wettability to oil-wetting sand. The change of wettability of the sand (initially water-wet) to an oil-wet sand will be achieved by soaking the sand in an oil bath at about 80°C for 3 to 6 weeks.

*Mathematical Modelling*

The experimental capillary pressure-saturation relations obtained for different wettabilities of the sand will be analyzed using the mathematical function proposed by Van Genuchten (1980). The Van Genuchten model has been applied widely in recent years because of its simplicity and its ability to describe observed retention data for a variety of soils and liquids. Further, the model permits then the derivation of an analytical expression for the relative permeability function (kr-S) in the two-phase water/air system. Lastly, the predicted kr-S function for water and air will be compared with the experimentally obtained data.

*Additional information*

The PhD proposal will be part of a close scientific exchange with the Center of Innovation for Flow through Porous Media, Department of Petroleum Engineering, University of Wyoming. The cooperation was initiated in 2019 during the sabbatical stay of G. Schäfer as Fulbright Research Fellow. Since January 2022, the **IRP (International Research Project) CONTINUUM** (Assessment of the effeCt Of wettability oN three-phase relaTive permeabIlities iN granUlar poroUs Media) is financial supported by the CNRS.

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