Study of solute transport in partially saturated porous media: influence of pore-scale physics on the macroscopic behavior

The partially saturated zone (vadose zone) plays an important role in many aspects of hydrology. In recent years interest in this area has increased due to growing concerns about the impact of industrial, agricultural and urban activities on the quality of the subsurface environment and particularly on drinking water resources. Groundwater may be contaminated by pesticides and fertilizers applied to agricultural land passing through the partially saturated zone as well as by chemicals migrating from urban and industrial sanitation sites. Depending on rainy and dry periods, the saturation in the vadose zone is variable and the transport of pollutants depends highly on the saturation. Furthermore, in the future, longer periods of drought are expected to alternate with intense rainfall events. Extrapolation from current scenarios will therefore be difficult and a better understanding of transport at very low saturation levels becomes crucial.

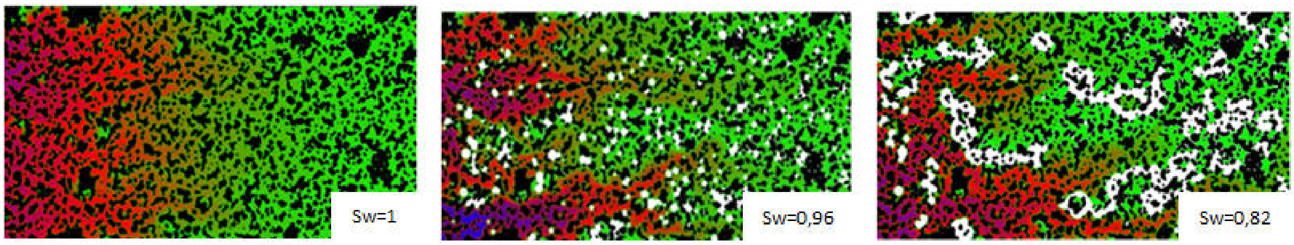

Figure : Tracer (red) experiments in unsaturated porous medium. The solid phase is shown in black, the wetting phase (water) in green and the non-wetting phase (air) in white.

Despite a number of studies, transport in partially saturated porous media is still poorly understood. Furthermore, there are widely divergent results in the literature regarding the dependence of the dispersion coefficient on saturation. The major difficulty lies in the fact that the pore volume accessible by the tracer depends on the physics of the underlying immiscible two-phase flow. Indeed, the spatial distribution of air and water in a porous medium depends on several structural and physico-chemical parameters including the interfacial tension between the two phases. For example, surfactant release from plant roots can induce a change in the interfacial tension and consequently influence the fluid distribution and thus transport. In addition, the heterogeneity of the medium as well as precipitation and evaporation strongly affect the phase distribution. In some situations, the connectivity of the immiscible phases is reduced and leads to displacement distributions of the molecules that differ from those of the classical dispersion model. The dispersion coefficients can then become time and/or space dependent. Thus, recent studies show that the stagnant zones created by the immiscible phases strongly affect transport. However, the influence of these areas and their consequences on the macroscopic transport equations requires further investigation.

The objective of this PhD work is to better understand the transport of solutes in partially saturated porous media (air-water) and the resulting macroscopic equations. The PhD thesis consists of an experimental part and a numerical part, both in continuation of previous work. In a first step, we will carry out air-water immiscible displacements in glass micromodels and mini-plugs of different geometries in order to study the influence of the pore structure as well as fluid properties (viscosity, IFT...) on the spatial distribution of air. In a second step, we will perform Lattice Boltzmann simulations of passive tracer transport in the images taken from the partially saturated micromodel. The simulation allows to impose precise boundary conditions necessary for the interpretation of the displacement moments. We will be particularly interested in low water saturations. Finally, we will attempt to establish a correlation between pore structure, saturation and macroscopic equations.

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