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Non-linear flow phenomena in a porous cylindric microtube

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The understanding of water transfer in heterogeneous porous media such as soils is at the center of many issues such as water resource management. In the macroporosity as opened cracks, earthworm burrows free surface flow can be a dominant (Sammartino et al., 2012). Very little is known about the physical processes involved in infiltration, whether it is the form of streamflow, continuous films in the macropore (Keven and Germann, 2013) or the "active" macroporosity during a flow and also the exchange mechanisms at the macropore interface (Katuwa et al., 2015). Answering these questions on a small scale is crucial because, for example, the filling rate of a macropore is closely related to colloid filtering, water retention phenomena. The last decades many models have been developed to model flow in macroporosity such as dual porosity with Kinetik Dispersive Waves models (Di Pietro et al., 2013) or conceptual approaches to film flow as in Nimmo et al. (2010). However, these models still do not explain all of the observed flows made by imaging techniques (Sammartino et al., 2015 ; Lissy, 2019).

In this paper, we focus on the modelling and simulating free surface flow in a cylindrical microtube taking into account the physicochemical properties of the matrix and at the interface between the matrix and the macropore. Indeed, organic matter is known to generally impart hydrophobic properties to soils. In an impervious microtube surface, a rich range of flow shapes has been identified: droplets, thin films or rivulets and notably, there is a regime leading to complete wetting (Beltrame, 2018). In the present work, the mesopore surface is porous and fluid transfer may appear through the interface between the macropore and the soil matrix.

The model is based on the long-wave approximation with a free surface. The soil matrix wettability is taking into account using disjoining and conjoining pressures as presented in Beltrame (2019). The linear classical flux condition on the liquid/porous interface as used in Ding and Liu (2011) does not yield if a hydrophobic coating is present: the flux depends on the matrix moisture too (Doerr et al., 2000). Our present model takes into account wettability at the surface and also in the porous matrix (Beltrame and Cajot, 2022). Thus, the dynamics, both in the matrix and in the macropore, are governed by a gradient type equation (Thiele, 2018) where free energy terms characterize the wettability.

Using numerical simulation and bifurcation diagrams, a rich behavior is brought to light. Notably, several flow regimes in a microtube are in competition and complex spatial organization appears showing clusters of annular drop trains. In addition, the interaction between the flow in micro-tube and the imbibition in porous matrix leads to non-linear phenomena. In particular, decreasing the saturation in the porous matrix may slightly increase the flow rate in the microporosity for specific parameters. This non-linear analysis highlights the crucial role of wettability in the fluid transfer.

Participation

In-Person

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