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Interplay of gravity, capillary and viscous forces on fluid volumes moving through a fracture

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Flow in unsaturated fractures and porous media is strongly dictated by the behavior of liquid-gas interfaces (menisci), which are a source of nonlinearity and give rise to phenomena such as intermittency and instability. The liquid-gas interface is responsible for the appearance of capillary forces and for a modified fluid-velocity profile, which yields an increased viscous dissipation per unit length. A reliable model of wetting and drying in fractures and porous media must be able to correctly describe the complex phenomena related to the presence of a moving interface.

In this paper we consider a fluid volume moving under the simultaneous influence of gravity, capillary and viscous forces. By means of numerical simulations based on the Volume of Fluid method, we investigate the interplay of these forces. We show that both a capillary drag force (due to hysteresis and to the velocity-dependent contact angle) and an increased viscous dissipation are responsible for a nonlinear relationship between the capillary number (viscous to capillary forces) and the Bond number (gravity to capillary forces). The numerical results are compared with theoretical derived scaling laws.