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Simulation of small-scale flow phenomena in fractured flow systems using Smoothed Particle Hydrodynamics

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The simulation of unsaturated flow in fractured media is a challenge because of local heterogeneities in the hydraulic parameter field of the flow system introduced by faults, joints and fissures. Flow velocities of water can differ by several orders of magnitude due to the presence of capillary and gravity driven free-surface flow. Volume averaged effective models such as the Richard's equation for unsaturated porous media fail to capture these small-scale flow features, but rather simulate flow in a representative elementary volume. In this work mechanisms controlling unsaturated flow in fractured media on local scale were studied with a three-dimensional Lagrangian smoothed particle hydrodynamics (SPH) model. The interpolation-based numerical approach uses particles to discretize the fluid. In contrast to grid-based models SPH allows the investigation of highly dynamical interfaces without the need of complex front-tracking algorithms such as in the VOF (Volume of fluid) method. The SPH model has been shown to accurately reproduce laboratory results for multiphase flow, including the effect of the surface tension and contact angle hysteresis (Dragila & Weisbrod 2004, Tartakovsky & Meakin 2005). Our model uses pairwise fluid-fluid and fluid-solid interaction forces to model surface tension and fluid-fluid-solid interactions. These forces are calibrated to simulate a wide range of wetting conditions. Depending on (1) model geometry (surface inclination), (2) surface/fluid properties (wetting conditions, contact angle) and (3) boundary conditions (constant flux, intermittent flux) we show that the model can simulate flow phenomena in fractured media encountered in laboratory experiments and is in agreement with analytical solutions. Different flow regimes (droplets, rivulets, film flow) as well as regime transitions are reproduced to quantify discharge in small-scale fractures from a specific input. The discrete particle-based flow field allows the characterization of transport relevant properties such as surface contact area and contact time.

References:
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