Validation of massively parallel free-surface SPH simulations of gravity-driven flow and partitioning dynamics at complex fracture intersections

Jannes Kordilla , Torsten Noffz, Geoscientific Centre, University of Göttingen, Germany
Alexandre Tartakovsky, Computational Mathematics Group, Pacific Northwest National Laboratory, Richland, USA

In this work we present low-Capillary number free-surface fracture-scale flow simulations obtained with a parallelized SPH model. In the model, surface tension and fluid-solid interactions are modeled with pairwise forces added into the SPH equation. The model is used to simulate free-surface flow dynamics including the effect of surface tension for a wide range of wetting conditions in smooth and rough fractures. The code employs an adaptive MPI domain decomposition to increase the computational efficiency in the presence of a sparsely populated domain. Due to the highly efficient generation of surface tension via particle-particle interaction forces, the dynamic wetting of surfaces can readily be obtained.

We used the model to simulate unsaturated flow observed in a fractured system. Flow velocities of water in porous geological media generally do not exceed a few millimeters per day. However, tectonic stresses commonly induce the formation of discontinuities, i.e. fractures, which allow much higher flow velocities. In the case of vertical, gravity-driven flows, this leads to a pronounced deviation from classical volume-effective descriptions and complicates the prediction of water movement for example in the context of nuclear waste repository sites, mining industry and in general water resources management. On fracture-scales the spatial and temporal distribution of flow modes and its influence on travel time distributions is still not very well understood. The complex interplay of flow modes such as droplets, rivulets, turbulent and adsorbed films and its relation to the geometrical properties of the system is difficult to model and requires efficient numerical methods.

We validated the model via empirical and semi-analytical solutions and conducted laboratory-scale percolation experiments of multiphase flow through synthetic fracture systems. The setup allows us to obtain travel time distributions and identify characteristic flow mode distributions on wide aperture fractures intercepted by horizontal fracture elements. The effect of flow mode formation on fracture partitioning dynamics is demonstrated.