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A 3D numerical model of hydraulic fracturing, injection pressure and microseismicity in anisotropic stress fields

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We present a 3D numerical model for hydraulic fracturing and damage of low permeable rock in an anisotropic stress field. The 3D numerical model computes the intermittent damage propagation, microseismic event-locations, microseismic event-distribution, damaged rock volume, and injection pressure. The model builds on concepts from invasion percolation theory, where cells in a regular grid are connected by transmissibilities, also called bonds. A numerical pressure solution provides the pressure in each cell at each time step during the hydraulic fracturing operation. The numerical solution is based on a cell-centered finite volume scheme. A fast version of the numerical scheme is suggested by restricting fluid flow to the damaged rock volume. The hydraulic fracture and the damaged rock volume propagate by one cell when a bond breaks. An intact bond breaks when the fluid pressure exceeds the least compressive stress and a random uniformly distributed bond strength. The model is different from a pure invasion percolation model by using the fluid pressure in combination with a random bond strength to decide which bond to break, instead of only the random strength. The volume of damaged rock is estimated with a simple expression for cases with high permeability of the damaged rock volume. The model is tested with a published case from the Barnett Shale. It reproduces the observed main features of the Barnett case, such as the spatial and temporal distribution of the events, the magnitude – frequency distribution and the injection pressure. It is found that the microseismic event-distribution and the b-value depend on the permeability of the damaged rock volume. The b-value increases with decreasing permeability from 0.6 to a value above 2 for the maximum possible permeabilities. The damaged rock volume is non-compact and similar to a percolation cluster for “high” damaged rock permeabilities, and it becomes increasingly compact with decreasing permeabilities. The resulting loop-less fracture network is found to have similar characteristics for different damaged rock permeabilities.