A pore-scale approach of two-phase flow in deformable porous media

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ABSTRACT

We propose a pore-scale numerical model to simulate the drainage process in porous materials aiming at fully coupling the two-phase flow and the deformation of solid media. The solid phase is idealized as dense random packings of polydisperse spheres, generated with the discrete element method (DEM)[1]. The pore space is conceptualized as a network of pores connected by throats which is obtained by using regular triangulation technique based on our previous research[2].

The method is applied to the quasi-static regime, simulating primary drainage of initially saturated granular materials. Theoretical formulas for calculating geometrical properties and entry capillary pressure for given pores are developed by extending the Mayer and Stowe-Princen (MS-P) theory of drainage [3, 4, 5]. Such relationships are employed in the network for defining as local invasion criteria, so that the drainage can be represented by the replacement of W-phase when the threshold value is reached. During drainage, the forces acting on the solid phase induced by local NW-phase, W-phase and NW-W interfaces are determined consistently with the invasion criteria and local pore geometry. We implement these forces in our DEM code. The evolution of two-phase flow and deformation of solid skeleton can be attained, finally.

To accommodate different experimental situations, the model can be applied in optional side boundary conditions, i.e., the pore throats of side boundary can be considered open or closed. The events of W-phase entrapment are also considered during the coupling procedures. We verify the model by comparing simulation results with experimental data of quasi-static drainage experiments in a synthetic porous medium [6]. The simulated capillary pressure-saturation curve in primary drainage is in agreement with the experimental one. The model is applied to examine the question of effective stress in unsaturated materials and investigate the relationship between effective stress parameter χ and saturation. The result evidences a seemingly trend for coefficient χ to follow the variation of the saturation, especially at a low water content. A detailed analysis of microscale strain, stress and W-phase saturation confirms this relationship with poroelasticity.

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