Effective Hydraulic Properties of Porous Media by Pore-Scale Smoothed Particle Hydrodynamics Analysis

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We analyse porous materials with respect to their intrinsic permeabilities, or generally speaking their hydraulic properties, by means of pore level fluid flow simulations using Smoothed Particle Hydrodynamics (SPH). The SPH analysis is based on the (quasi-incompressible) Navier-Stokes equations. While such CFD problems were traditionally tackled using established Eulerian grid-based methods, the mesh-free Lagrangian SPH method is observed to gain an increasing amount of attention in research [1, 2].

Its attractiveness is accounted for by several circumstances: 1. While mesh- or grid-based methods are prone to extensive pre-processing routines when it comes to discretizing arbitrarily complex pore structure domains, the associated overhead in SPH is fairly neglectable. 2. Within a suitable algorithmic framework, computational costs scale approximately linear with DOFs. 3. Without the necessity of using interface tracking methods, SPH per se supports its application to multiphase problems such as flow in oil-water saturated petroleum reservoirs. 4. Due to its Lagrangian nature, SPH provides -to a certain extent- intrinsic stability for highly advective flow, i.e. flow regimes where traditional methods require the application of stabilization techniques.

The latter is of particular relevance within the scope of this work. Upon providing SPH based benchmark results for Darcy-type creeping flow through 3D periodic grain structures [SC, FCC, BCC lattices] consistent with literature results [3] for validation purposes, we analyse hydraulic properties at increasing filter velocities. Thereby we observe a transition (at RE ≈ 1) from viscous forces dominated flow consistent with Darcy to inertial forces affected flow which is beyond the scope of validated macroscopic theories based on a viscous momentum interacion between the solid skeleton and the viscous pore fluid. [4]. We perform a dimensional analysis to distinguish and ultimately characterize different flow regimes. Subsequently, we exemplify the application of SPH to estimate intrinsic permeabilities of geological rock structures based on morphological data obtained by μCT measurements.

References

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