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Discontinuous Galerkin approximation of flows in fractured porous media on polytopic grids

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We propose a new formulation based on discontinuous Galerkin (DG) methods in their generalization to polytopic grids for the simulation of flows in fractured porous media. The method that we propose is very flexible from the geometrical point of view, being able to handle meshes made of arbitrarily shaped elements, with edges/faces that may be in arbitrary number (potentially unlimited) and whose measure may be arbitrarily small. Therefore, our approach is very well suited to tame the geometrical complexity featured by most of applications in the computational geoscience field, such as petroleum engineering, nuclear waste storage, geothermal energy, etc. More precisely, we adopt a model for single-phase flows, that is valid for fractures with both large and low permeability. This model considers the case of a single fracture, treated as a (d -1)-dimensional interface between two d-dimensional subdomains, d = 2, 3. The flow in the porous medium is assumed to be governed by Darcy's law and a suitable reduced version of this law is formulated on the surface modelling the fracture. Physically consistent coupling conditions are added to account for the exchange of fluid between the fracture and the porous medium. We focus on the numerical approximation of the coupled bulk-fracture problem, employing Discontinuous Galerkin finite elements on polytopic grids. The choice of DG methods arises spontaneously in view of the discontinuous nature of the solution at the matrix-fracture interface. However, this is not the only motivation. Indeed, the interface conditions can be naturally formulated using jump and average operators and embedded in our variational formulation, so that DG methods turn out to be a very powerful approach for handling the (weak) coupling of the two problems. We theoretically analyze our discrete formulation, prove its well-posedness and derive optimal a priori error estimates in a suitable (mesh-dependent) energy norm. Finally, we consider both benchmark test cases with analytical solution and a realistic example driven by petroleum engineering applications, namely the quarter five-spot problem. We demonstrate that our scheme can efficiently handle both situations.

References

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