

RECENT ADVANCES IN NUMERICAL METHODS FOR POROMECHANICS AND THEIR APPLICATIONS

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ABSTRACT

Poromechanics provides the mathematical foundation for modeling the coupled interaction between deformable porous media and fluid flow. These models play a central role in a wide range of applications, including geomechanics, petroleum engineering, biomechanics, geothermal energy, groundwater flow, hydrogen storage, and carbon capture and storage. The resulting systems of partial differential equations are inherently multiphysics in nature and pose significant computational challenges due to heterogeneous materials, multiscale phenomena, nearly incompressible behavior, nonlinear constitutive laws, and complex geometries. Addressing these challenges requires numerical methods that provide high accuracy, stability, and computational efficiency while preserving the essential physical and mathematical properties of the coupled system.

Recent years have witnessed remarkable advances in the development, analysis, and implementation of robust and efficient numerical methods for poromechanics. In particular, significant progress has been made in the development of high-order numerical methods, including mixed finite element, discontinuous Galerkin, finite volume, virtual element, hybrid high-order, and structure-preserving discretizations, leading to improved stability, accuracy, and computational efficiency. These methods offer promising approaches for accurately approximating coupled flow and deformation while accommodating complex geometries and heterogeneous media. Their rigorous analysis raises important questions concerning stability, convergence, parameter robustness, mass conservation, and the regularity of the exact solution. Moreover, modern computational techniques such as adaptive mesh refinement, a posteriori error estimation, multiscale methods, domain decomposition, efficient iterative solvers, uncertainty quantification, and machine learning have broadened

the scope of numerical simulations for coupled porous media problems. The combination of high-order discretizations with the above-mentioned techniques offers opportunities to improve computational accuracy and reduce the overall cost of large-scale simulations.

The aim of this minisymposium is to bring together researchers working on the mathematical analysis, numerical approximation, and scientific computing aspects of poromechanics. Particular emphasis will be placed on the design, analysis, and application of high-order discretizations for coupled porous media problems. The session will provide a forum for presenting recent advances in numerical methods and their applications to challenging problems arising in geosciences, environmental engineering, biomechanics, and energy systems. Contributions addressing the interplay between high-order approximation, stability, error control, and computational efficiency are particularly welcome. Topics of interest include, but are not limited to:

- High-order mixed finite element, discontinuous Galerkin, hybrid high-order, and virtual element methods;
- Structure-preserving discretizations;
- Stability, parameter robustness, and a priori and a posteriori error analysis of high-order methods;
- Adaptive algorithms and multilevel methods;
- Efficient iterative solvers and preconditioning techniques;
- Multiscale and multiphysics poromechanics;
- Applications to subsurface flow, geomechanics, biomechanics, geothermal energy, hydrogen storage, and carbon capture and storage.

SPEAKERS

1. Michele Botti (Politecnico di Milano): Iterative and non-iterative sequential schemes for polyhedral discretizations of poroelasticity and thermo-poroelasticity problems.
2. Christian Kreuzer (Technische Universität Dortmund): Inf-sup stable discretizations for the Biot problem.

3. Jeonghun Lee (Baylor University, USA): Splitting methods for fluid and poroelastic structure interactions.
4. Nicolás A. Barnafi (Pontificia Universidad Católica de Chile): Finite elements approximations of constrained Q-tensors
5. Lina Zhao (City University of Hong Kong): A structure-preserving discretization for the coupled Stokes-Biot equations.
6. Sarvesh Kumar (Indian Institute of Space Science and Technology (IIST)): Three and Four Fields Mixed Formulations for the Approximation of Poroelasticity
7. Jesus Vellojin (Universidad Técnica Federico Santa María – Sede Viña del Mar): A virtual element method for the Biot-Brinkman equations using Nitsche's technique
8. Arbaz Khan (IIT Roorkee): Distributed optimal control problems governed by poroelasticity equations