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A study of optimal control problems for transport processes in porous media: analysis and homogenization

Abstract

The study of transport phenomena in porous media plays a crucial role in many scientific and engineering applications such as environmental processes, subsurface flow, energy systems and biological transport. This abstract focuses on the mathematical analysis of optimal control problems arising in models that describe diffusion, reaction and phase-field phenomena in porous medium.

Abstract begins with the investigation of an optimal control problem governed by a system of diffusion–reaction equations in a porous medium. Distributed control variables are introduced, and the objective is to minimize a quadratic cost functional. The existence of optimal controls and the corresponding optimality conditions are established. Furthermore, a homogenized formulation of the control problem is derived to capture the effective macroscopic behavior of the heterogeneous medium and the convergence of the microscopic solutions toward the homogenized limit is rigorously analyzed.

Next, we addresses an optimal control problem associated with a diffusion–reaction–precipitation system in a porous medium, where chemical reactions take place at the interfaces of solid structures. The model describes one-sided reactions in which multiple chemical species contribute to the formation of precipitates on solid surfaces. For this system, the existence of optimal controls and their characterization are rigorously proven. The

corresponding homogenized optimal control problem is then derived and a detailed convergence analysis is discussed.

Finally, an optimal control problem related to phase-field modeling of two incompressible fluids is considered. The mathematical model consists of a coupled system involving fluid flow equations and phase-field dynamics. The well-posedness of the coupled system is established, along with the existence of an optimal control. Necessary optimality conditions are derived through the analysis of the associated adjoint system.