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A Time-Filtered VMS-POD Reduced-Order Model for Double-Diffusive Darcy-Brinkman Equations

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Abstract

Double-diffusive Darcy-Brinkman equations are driven by two scalar fields with different diffusion rates. To model porous medium effects, a Darcy term is included in the momentum equation. Since the physical model consists of a coupled system of momentum, heat, and mass transfer equations, its numerical simulation is computationally demanding. Additionally, full-order numerical methods often lead to large algebraic systems and a high computational burden. Thus, efficient reduced-order techniques are required to significantly reduce the computational cost while maintaining numerical accuracy and robustness.

Proper Orthogonal Decomposition (POD)-based reduced-order models (ROMs) have become a popular approach for reducing the computational complexity of such problems. POD constructs a low-dimensional approximation that preserves the dominant dynamics of the original system [1, 2]. Another challenge arises as the Rayleigh number increases, causing convection cells to form and the flow to become more turbulent. To address this issue, a projection-based Variational Multiscale (VMS) method will be employed to improve numerical stability while preserving the accuracy of the reduced-order model [1].

We extend the method proposed in [3] to solve the double-diffusive Darcy-Brinkman equations. The resulting framework combines POD, projection-based VMS stabilization, and a time-filtering technique. The stability and error analyses of this method are presented, and its performance is demonstrated through benchmark test problems. Numerical results indicate that this approach improves temporal accuracy and energy preservation without increasing process time. The proposed method provides a robust, stable, and accurate reduced-order approach for the simulation of double-diffusive Darcy-Brinkman flows.

Keywords: Proper orthogonal decomposition, variational multiscale method, time filtering.

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