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Thermosolutal Convection in Dual-Porosity Media With Generalized Boundary Conditions and Magnetic Field Effect

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ABSTRACT

This study offers an in-depth examination of thermosolutal convection stability in dual-porosity media, emphasizing the influence of chemical hydrodynamics under a magnetic field. The governing equations are formulated based on fundamental principles of fluid mechanics and chemical kinetics, encapsulating the interplay between convection and reaction rates. In addition, we formulated generalized boundary conditions that explicitly incorporate the influence of the gradients in both solute concentration and temperature on the boundary layers, thereby enhancing the theoretical model's realism and extending their applicability. In this context, two algorithms have been developed for studying linear instability and nonlinear stability, utilizing Chebyshev collocation methods to ascertain stability boundaries and delineate the system's linear and nonlinear behaviors. Ultimately, extensive parametric studies reveal that the interplay between thermal and solutal gradients, further modulated by magnetic field-induced chemical reactions, fundamentally dictates the instability and stability thresholds of the critical thermal Rayleigh number, signifying the onset of convective instability and stability. In fact, this study offers assistance in understanding the complex interactions of these effects in double-diffusive convection within dispersive porous media, thus enhancing applications in environmental engineering and materials processing.

1 | Introduction

Double-diffusive convection denotes the concurrent transfer of heat and solute via temperature and concentration gradients, a phenomenon that is pivotal in numerous natural and chemical processes [1, 2]. This form of convection is prevalent in systems where mass and heat transfer occur synchronously, including geophysical fluid dynamics [3], oceanography [4], astrophysics [5], and numerous engineering applications, such as chemical reactors and heat exchangers [6–9]. In fact, the structural characteristics of double porosity materials exhibit both conventional macroporosity, as described in porous media theory, and microporosity arising from cracks or fissures within the porous framework. This dual-scale architecture not only governs fluid transport and heat transfer processes in a fundamentally different manner than single porosity media but has also inspired a wealth of theoretical, numerical, and experimental studies on thermal convection in double porosity systems, which is of considerable importance and has garnered significant interest [10–23]. The laboratory synthesis of bidispersive porous materials has been evidenced, as articulated by Nield and Kuznetsov [24]. However, thermal and mass transmission in bi-disperse porous materials has been extensively investigated in chemical engineering collected works, as demonstrated by the works of Valuš and Schneider [25], Burghardt et al. [26], and Szczygieł [27]. The intrinsic characteristics of these effects and their importance in various geophysical and engineering

Abbreviations: ANA, anti-nuclear antibodies; APC, antigen-presenting cells; IRF, interferon regulatory factor.