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Evolution and Merging of Double-Diffusive Layers in a Vertically Stable Compositional Field

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Abstract : The phenomenon of double-diffusive convection is driven by density gradients created by two different components (e.g., temperature and concentration) having different molecular diffusivities. The evolution of horizontal double-diffusive layers (DDLs) is one of the outcomes of double-diffusive convection occurring in a laterally/vertically cooled rectangular cavity having a pre-existing vertically stable composition field. The present work mainly focuses on different characteristics of the formation and merging of double-diffusive layers by imposing lateral/vertical thermal gradients in a vertically stable compositional field. A CFD-based twodimensional fluent model has been developed for the investigation of the aforesaid phenomena. The configuration containing vertical thermal gradients shows the evolution and merging of DDLs, where, elements from the same horizontal plane move vertically and mix with surroundings, creating a horizontal layer. In the configuration of lateral thermal gradients, a specially oriented convective roll was found inside each DDL and each roll was driven by the competing density change due to the already existing composition field and imposed thermal field. When the thermal boundary layer near the vertical wall penetrates the salinity interface, it can disrupt the compositional interface and can lead to layer merging. Different analytical scales were quantified and compared for both configurations. Various combinations of solutal and thermal Rayleigh numbers were investigated to get three different regimes, namely; stagnant regime, layered regime and unicellular regime. For a particular solutal Rayleigh number, a layered structure can originate only for a range of thermal Rayleigh numbers. Lower thermal Rayleigh numbers correspond to a diffusion-dominated stagnant regime. Very high thermal Rayleigh corresponds to a unicellular regime with high convective mixing. Different plots identifying these three regimes, number, thickness and time of existence of DDLs have been studied and plotted. For a given solutal Rayleigh number, an increase in thermal Rayleigh number increases the width but decreases both the number and time of existence of DDLs in the fluid domain. Sudden peaks in the velocity and heat transfer coefficient have also been observed and discussed at the time of merging. The present study is expected to be useful in correlating the double-diffusive convection in many large-scale applications including oceanography, metallurgy, geology, etc. The model has also been developed for three-dimensional geometry, but the results were quite similar to that of 2-D simulations.

Keywords : double diffusive layers, natural convection, Rayleigh number, thermal gradients, compositional gradients
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