

Asymmetric buoyancy-driven fingering in reactive systems

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Buoyancy-driven instabilities in fluids are genuine sources of fluid motions. The well known Rayleigh-Taylor (RT) instability occurs as soon as a denser solution overlies a less dense one in the gravity field like typically when salted water sinks into fresh water. This instability has been the subject of numerous studies as it impacts numerous climatic, environmental and industrial applications. The double-diffusive (DD) instability is another buoyancy-driven instability which arises when two different contributions to the density profile are opposing (classically heat and mass but it can also be that of two different solutes). DD occurs when the total density profile is stable (i.e. density increases downwards along the gravity field) but the destabilizing component (heat for instance) diffuses faster than the stabilizing one (mass). It leads to convective motions that have been well studied in oceanography (where it leads to so-called “salt fingers”), geology or in the analysis of convection in star or planet mantles for instance.

In some applications like industrial processes, CO₂ storage or thermonuclear burning of stars for instance, such convective motions may interplay with chemical reactions when the reaction dynamically modifies a physical property of the flow like its density. Our objective is to study the influence of such active chemical reactions on buoyancy-driven flows and analyze to what extent the symmetries and properties of the RT and DD fingers are modified by the reactions.

In this context, we study here by combined experimental and theoretical analysis the influence of a simple $A+B\rightarrow C$ chemical reaction on buoyancy-driven Rayleigh-Taylor and double diffusion instabilities. We consider a stratification of a solution of reactant A on top of a miscible solution of reactant B within a Hele-Shaw cell oriented vertically in the gravity field. In absence of reaction, a RT instability is obtained if the density ρ_A of the upper solution is larger than the density ρ_B of the lower one. If we start from an initially statically stable configuration ($\rho_A < \rho_B$), DD modes are obtained if B diffuses sufficiently faster than A. If A reacts with B to yield the product C, then the density profile is affected in space and time by the reaction.

We demonstrate that, in that case, the reaction can have a profound influence on the dynamics as it breaks the symmetry of the RT and DD patterns [1]. Indeed, instead of deforming the miscible interface symmetrically around the position of the initial contact line, the convective structures develop only above it. In some cases, a second structure appears later in time and can be attributed to the dynamic generation of the product C in the course of time. We analyze the changes in patterns by comparing experiments done using non-reactive solutions and reactive acid-base systems. We quantitatively compute the amplitude of the symmetry breaking as a function of the relative concentrations of the two reactants A and B. We enlighten the experimental results by numerical simulations of a reaction-diffusion-convection model of buoyancy-driven convection triggered around an $A+B\rightarrow C$ reaction-diffusion front using values of parameters dictated by the experiments. Good agreement between both experimental and numerical results is obtained.

Références

1. L. LEMAIGRE, M.A. BUDRONI, L.A. RIOLFO, P. GROSFILS, A. DE WIT, Asymmetric Rayleigh-Taylor and double-diffusive fingers in reactive systems, *Physics of Fluids*, in press (2013).