Long-wave instability of a multicomponent fluid layer with Soret effect

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The long-wave instability of a vertical layer filled with a multicomponent fluid is investigated. In the basic stationary state, a constant temperature difference between the lateral walls results in linear temperature profile in the cross-section, which in turn induces linear profiles of concentrations due to the Soret effect. The corresponding density distribution leads to the appearance of a plane-parallel flow in vertical direction due to gravity. This configuration can be related to the thermogravitational column at the initial stage of the separation process (when there are no vertical concentration gradients).

The key dimensionless parameters of the problem are the net separation ratio Ψ, which describes the relative importance of contributions from compositional and thermal gradients to the density gradient, and $n-1$ separation ratios ψ_i of the mixture components (here n is the total number of components). If a particular component segregates to hot (cold) side due to the Soret effect, then the corresponding separation ratio is positive (negative) provided that the heaviest component is chosen as a solvent. In addition, we also have $(n-1)^2$ dimensionless parameters expressed through the diffusion coefficients. It is shown that the cross-diffusion effects can be excluded by introducing new concentrations and separation ratios. This transformation preserves the boundary conditions, which allows us to reduce the original stability problem to the problem without cross-diffusion.

It is found that the long-wave instability is caused by the interplay between the main flow and the concentration waves, which have a long scale in vertical direction and produce non-uniform density stratification. These waves decay in an isothermal fluid layer. When the lateral heating is applied, the development of perturbations depends on the eigenvalues of diffusion matrix and the separation ratios of components. In the general case of n-component mixture, several stable regions in the parameter space are identified. When all components have identical diffusive properties (eigenvalues), the instability is observed only in the range $-1 < \Psi < -1/2$. The complete analysis is performed for the case of ternary fluid. It is shown that the onset of instability can be monotonic or oscillatory depending on the values of parameters. The difference between the diffusive properties of components leads to the enlargement of instability region in the parameter space. The critical Grashof numbers are plotted and their behaviour is discussed.

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