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Phase coexistence in thin liquid films stabilized by colloidal particles: equilibrium and non-equilibrium properties

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Phase equilibria between regions of different thickness in thin liquid films stabilized by colloidal particles are investigated using a quasi-two-dimensional thermodynamic formalism. Appropriate equilibrium conditions for the film tension, normal pressure, and chemical potential of the particles in the film are formulated, and it is shown that the relaxation of these parameters occurs consecutively on three distinct time scales. Film stratification is described quantitatively for a hard-sphere suspension using a Monte-Carlo method to evaluate thermodynamic equations of state. Coexisting phases are determined for systems in constrained- and full-equilibrium states that correspond to different stages of film relaxation. We also evaluated the effective viscosity coefficients for two-dimensional compressional and shear flows of a film and the self and collective mobility coefficients of the stabilizing particles. The hydrodynamic calculations were performed using a multiple-reflection representation of Stokes flow between two free surfaces. In this approach, the particle-laden film is equivalent to a periodic system of spheres with a unit cell that is much smaller in the transverse direction than in the lateral direction.