

DIFFUSE INTERFACE METHODS FOR COMPLEX FLOWS WITH IMMISCIBLE MATERIALS

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ABSTRACT

Flows with immiscible materials occur in many areas, including industrial and natural applications such as spray atomization, oil-water separation, ink-jet printing, cloud formation, and so on. In some cases, for example in metallurgy, the flows are slow and the interfaces do not become excessively corrugated. However, in many other cases, such flows are driven by fluid instabilities and / or occur in the presence of background turbulence. Then, the sharp interfaces between immiscible fluids undergo complex morphological changes including interface breakup and reconnection, which significantly reduce our abilities to accurately predict these flows. Another challenge in such flow systems is that the fluid properties, like atomic mass and viscosity, change abruptly across the interface, making accurate simulations of flows with immiscible materials even more difficult.

Diffuse interface (or phase-field) methods, such as Cahn-Hilliard formulations, have become a central tool for modeling flows involving immiscible materials. Their importance stems from replacing sharp, explicitly tracked interfaces with a finite-thickness transition region governed by continuous fields. This avoids the geometric complexity of interface reconstruction in sharp interface approaches (e.g., front tracking, VOF, or level set methods) and naturally accommodates topological changes like breakup and coalescence. Surface tension forces arise directly from a free-energy functional, avoiding noisy curvature calculations that can degrade accuracy in sharp interface methods and ensuring thermodynamic consistency. Moreover, phase-field formulations provide a unified framework for coupling interfacial dynamics with additional physics—such as phase change, chemical reactions, or electric fields—without introducing separate interface conditions.

Despite their advantages, important challenges remain. A central issue is the use of artificially thick interfaces for numerical tractability, which complicates the connection to the sharp-interface limit and may affect accuracy. High density and material property ratios can introduce numerical stiffness and instability. Further open questions include generalizations to compressible multi-component flows, coupling with turbulence models, and the development of efficient adaptive methods to reduce computational cost while preserving accuracy.

The minisymposium offers a venue to discuss the latest generalizations and applications of diffuse interface methods, as well as recent developments in robust numerical implementations.