Modeling Development for Free Surface Flow with Phase Change

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Development of predictive capability for free surface flow with phase change is essential to evaluate liquid wall protection schemes for various fusion chambers. Wtih inertial fusion energy (IFE) concepts, such as HYLIFE-II, rapid condensation into cold liquid surfaces is required when using liquid curtains for protecting reactor walls from blasts and intense neutron radiation. With magnetic fusion energy (MFE) concepts, droplets are injected into the free surface of the liquid to minimize evaporation by minimizing the surface temperature. This paper presents a numerical methodology for free surface flow with heat and mass transfer to help resolve feasibility issues encountered in the aforementioned fusion engineering fields, especially spray droplet condensation efficiency in IFE and droplet heat and mass transfer enhancement on free surface liquid divertors in MFE.

The numerical methodology is being conducted within the frame work of the incompressible flow with heat and mass transfer model. We present a new second order projection method, in conjunction with Approximate-Factorization techniques (AF method), for incompressible Navier-Stokes equations. A smoothing function is introduced for the piecewise constant density, viscosity and temperature. The Crank-Nicholson method was used for the diffusion term to eliminate the numerical viscous stability restriction and 3rd order ENO scheme used for the convective term to guarantee the accuracy of the method. A four-level V cycle multigrid algorithm for pressure Poisson equation is used in order to decrease computation time. To capture the free surface of the flow and the deformation of the droplets accurately, we use the level set method by S. Osher and J.A. Sethian. The level set approach has two inherent strengths. One very useful feature is that the representation of the interface as the level set of some function ϕ leads to convenient formulas for the interface normal direction and curvature. Another advantage of this approach is that no special procedures are required in order to model topological changes of the front. This numerical investigation identifies the physics characterizing transient heat and mass transfer of the droplet and the free surface flow. The results show that with the deformation of the droplet and topological changes of the free surface, the heat and mass transfer can be enhanced significantly.