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Development of a 2-D model to simulate convection and phase transition efficiently

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We present a two-dimensional convection phase change model using the incompressible Navier-Stokes equation set and enthalpy as the energy conservation variable. Significant algorithmic challenges are posed for problems of phase change interfaces within convective flow regimes. The equation set is solved with the Jacobian-Free Newton-Krylov (JFNK) nonlinear inexact Newton's method. SIMPLE, a pressure-correction algorithm, is used as a physics-based preconditioner. This algorithm is compared to solutions using SIMPLE as the main solver.

Algorithm performance is assessed for a benchmark problem, phase change convection within a square cavity of a solid pure material cooled below the melting temperature. A time step convergence analysis demonstrates that the JFNK model with second order discretization is second order accurate in time. A Gallium melting simulation is also performed and evaluated; in this configuration multiple roll cells develop in the melted region at early times when the aspect ratio is high. The JFNK-SIMPLE method is shown to be more efficient per time step and more robust at larger time steps when compared to SIMPLE as the main solution algorithm. Overall CPU savings of more than an order of magnitude are realized.

As a further analysis of JFNK-SIMPLE, multigrid is wrapped around SIMPLE, so SIMPLE acts as the smoother within a multigrid preconditioner to JFNK. For phase change conduction, additional gains in efficiency can be accomplished. When SIMPLE is incorporated as a preconditioner and smoother within JFNK, the ability to model more complex and realistic phase change convection problems with increased robustness and efficiency is achieved.