

Numerical investigation of melting solid spheres under forced convection

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Melting processes play a critical role in diverse fields such as oceanography, astrophysics, and metallurgy. Under forced convection, the flow alters the temperature distribution in the liquid phase, forming complex interface morphologies that, in turn, influence the flow as dynamic boundaries. Understanding the mechanisms behind this flow-melting interplay is essential for advancing knowledge of both natural and industrial processes. For instance, accurately modeling iceberg melting under ocean currents is crucial for improving melt parameterizations and predicting iceberg deterioration. Building on our recently developed sharp-interface method¹, we perform direct numerical simulations (DNS) of the melting dynamics of solid spheres in a warmer liquid driven by uniform flow. The solid and liquid phases are assumed to consist of the same pure substance. Successive regimes for the flow past a solid sphere—namely, axi-symmetric flow, plane-symmetric flow, 3D periodic flow characterized by vortex shedding, and chaotic flow—are observed at increasing global Reynolds numbers (Re) when melting is turned off. In the present of the melting, the front face remains axi-symmetric, with curvature distribution depending on Re , while the back end develops a melting-induced interface morphology that strongly couples with adjacent flow structures. Quantitatively, the volume evolution of the remaining solid approximately follows a quadratic power law, as predicted by Huang et al.², with small but predictable deviations related to Re and the wake structure. We define an effective Reynolds number, Re_e , based on the effective diameter of the shrinking cross-stream face. The effective drag force is higher than the classical curve for non-melting cases. For cases with $Re \geq 240$, beyond the first bifurcation, the induced effective lift force decreases and eventually reverses direction. These behaviors are closely related to the irregular front shape and the induced vortical structures. Finally, the transition between different flow regimes is investigated, and geometry-related hysteresis is reported during the melting process, as Re_e decreases.



Figure 1: Snapshot of a melting solid in the chaotic regime.

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¹Xue et al., *Journal of Computational Physics*, **491**, 112380 (2023)

²Huang et al., *Journal of Fluid Mechanics*, **765**, R3 (2015)