Worster, M. Grae; Peppin, S. S. L.; Wettlaufer, J. S.
Colloidal mushy layers. (English) Zbl 1461.76450

Summary: We consider the solidification of idealised two-component mixtures comprising a solvent or suspending fluid and dissolved solute molecules or suspended colloidal particles, each considered as hard spheres. We review some fundamental thermodynamic ideas regarding relative motion between species and phase equilibria in such mixtures to show how the related solid-liquid phase diagrams depend on the size of the spheres. Using similarity solutions, we first describe freezing of the solvent to form a pure solid (here referred to as ‘ice’), with the solute rejected from the solid forming a boundary layer or dense particle layer ahead of the freezing front. We extend ideas of constitutional supercooling to the case of colloidal suspensions and show that, for a given temperature difference driving solidification, constitutional supercooling occurs only for an intermediate range of particle sizes. Constitutional supercooling promotes the formation of a mushy layer in which segregated ice separates regions of concentrated solute or particles on the microscale. We formulate a continuum model of the mushy layer that relies on a key observation that the regelative motion of concentrated clusters of particles is independent of the size and geometry of the cluster. Our modelling begins with a description of relative motion as a Fickian diffusive process. However, at high particle concentrations, we show that it is more convenient and more computationally tractable to use an equivalent formulation in terms of Darcy flow of the solvent. Within a mushy layer these diffusive fluxes correspond directly to the regelative flux of particle clusters at a rate determined by the local temperature and temperature gradient.

MSC:
76T06 Liquid-liquid two component flows
80A32 Chemically reacting flows

Keywords:
colloids; solidification/melting

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References:


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