

MODELING OF PHASE TRANSITION OF PARTIALLY MISCIBLE SOLVENT SYSTEMS: HYDRODYNAMICS AND HEAT TRANSFER PHENOMENA

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ABSTRACT

The progress in the miniaturization of electronic chips is hampered by the requirement to remove very large amount of heat per unit surface and/or per unit volume. To enable efficient cooling, the focus of the heat transfer community has shifted from air cooling to single and two-phase (boiling) liquid cooling. However, the limitations of Critical heat Flux (CHF) in boiling systems is crucial in micro channels, when the size of the bubble reaches the channel diameter already before its detachment and earlier dry-out occurs. When considering the combined effects of heat removal, operating pressure losses, operational stability and device fabrication efforts, single-phase convective heat transfer appears to be the most promising concept. It was experimentally shown that single-phase convective heat transfer rates can be significantly enhanced during phase separation of partially miscible solvent systems [Ullmann et al., 2014]. Such solvent systems possess a Critical Solution Temperature (CST), and can alter from a state of a single liquid phase, to a state of two separated liquid phases by varying the temperature. During phase separation the system evolves from the non-equilibrium state to an equilibrium thermodynamic state through a sequence of highly inhomogeneous states, which are far from equilibrium. In low viscosity liquids and/or deep quench, convection is driven by non-equilibrium capillary (Korteweg) force which enhances coalescence among droplets/patches of the discontinuous phase. The resulting movement during the separation process lead to the enhancement of heat transfer rates [Gat et al, 2009, Segal et al., 2012].

As the interface between the separating phases is initially non-existing and gradually evolves in time, the modelling and simulation of the phase separation process can be carried out via the diffuse interface approach, where all properties are considered to vary continuously over the diffuse interface. Most of the simulation efforts assume instantaneous quench of the solvents to the final temperature, and therefore isothermal conditions are imposed in the simulation domain [Gat et al., 2009]. To simulate more realistic conditions of non-uniform temperature field, we developed a numerical model for phase separation of binary Upper CST mixtures confined between two opposite cooled walls. With a critical composition, the initial homogeneous mixture undergoes spinodal decomposition, when the walls are cooled below the critical temperature. The governing equations, which include the pertinent energy equation, were presented in Segal et al. [2012] and preliminary results were presented. Here, a new formulation is suggested for the typical length scale (a) of the spatial inhomogeneity that is included in the generalized free energy coarse-grained Landau-Ginzburg functional. The new formulation, which is based on physical considerations,

accounts for the temperature variation of this length scale. This temperature dependency is crucial for simulating spinodal decomposition across the critical point under non-isothermal conditions.

Special attention is also given to the formulation of the boundary conditions used in previous published works. We show that the commonly used boundary conditions fail to comply with the mass conservation requirement and remediation of this problem is suggested. The numerical model is used for simulating the separation process and to obtain the velocity, concentration and temperature fields. The numerical model is used for simulating the separation process and to obtain the velocity, concentration and temperature fields. The simulation results show the enhancement of the heat flux through the walls compared to quenching without phase separation. The mechanisms leading to the heat transfer enhancement are elaborated and discussed.

REFERENCES

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