Nano Heat and Mass Transfer Inside Carbon Nanotubes and in Nanosuspensions

A.L. Yarin
Faculty of Mechanical Engineering,
Technion – Israel Institute of Technology,
Haifa 32000, Israel
e-mail: meralya@yarin.technion.ac.il

Two problems arising in nanotechnology are discussed:
(i) The dynamic response -as caused by different means of thermal stimulation or pressurization- of aqueous liquid attoliter volumes contained inside carbon nanotubes is investigated theoretically and experimentally. The experiments indicate a radiation-driven mechanism responsible for the dynamic multiphase fluid behavior visualized with high spatial resolution using electron microscopy. The theoretical model is formulated using a continuum approach, which combines temperature-dependent mass diffusion with intermolecular interactions in the fluid bulk, as well as in the vicinity of the carbon walls. Intermolecular forces are modeled by Lennard-Jones potentials. Several one-dimensional and axisymmetric cases are considered. These include situations which physically represent liquid volume pinch-off, jetting or relocation due to thermal stimulation by a steady or modulated electron beam, as well as liquid precipitation (condensation) from vapor due to overcooling or pressurization. Comparisons between theoretical predictions and experimental data demonstrate the ability of the model to describe the major trends observed in the experiments.
(ii) Line evaporation of dense nanoparticle suspensions reveal interesting and non-trivial phenomena. The 2-D lines are drawn by a pen-like nozzle attached to a syringe containing a concentrated organic suspension (50% wt) of gold nanoparticles, which are encapsulated in surfactants to hinder agglomeration. Such particle-containing lines are of potential interest for microelectronic applications where circuits are written and heat-treated to dry off the organic solvent and sinter the nanoparticles, thus producing a continuous electrically-conducting path. The theoretical and experimental results show that particle deposits resulting from evaporative drying of these lines could be of non-uniform thickness with a dent in the middle and two humps on the sides of the cross-section. Formation of this undesirable landscape is attributed to the highly non-uniform evaporative character of sessile liquid lines, which results in a non-uniform consolidation of the porous precipitating phase formed by nanoparticles encased in organic surfactants. The presented description of the process in the framework of the consolidation theory dating back to soil mechanics yields the predicted deposit speck shapes, which are comparable to the experimental data.