Paper ID: 3266

MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM (A2)
Microgravity Experiments from Sub-orbital to Orbital Platforms (3)

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SELF-REWETTING HEAT TRANSFER FLUIDS AND NANO-BRINES FOR SPACE HEAT PIPES

Abstract

The role of surface tension becomes dominant in heat and mass transfer processes decreasing the Bo number, i.e. under microgravity conditions and/or reducing the systems size. In these processes, however, surface tension-driven flow has not drawn much attention from the heat transfer point of view, probably due to the fact that the direction of thermocapillary flow is normally from the regions of the interfaces at higher temperature towards lower temperature regions. If the direction of the flow becomes inverse, as in the case of "self-rewetting fluids, i.e. fluid mixtures with a non linear dependence of the surface tension with temperature, the situation can be drastically changed. Self-rewetting fluids include dilute aqueous solutions of high carbon number alcohols (e-g- Butanol, Pentanol, Exanol, Heptanol. etc.) that show surface tension minima versus temperature, and the temperature dependence turns out to be positive in the higher temperature region beyond the minima. Since these solutions are in non-azeotropic compositions, alcohol preferentially evaporates in the course of liquid/vapor phase change. The surface tension gradient nearby the three-phase interline, caused by both temperature and concentration gradients, is responsible for spontaneous liquid inflow directed towards hot spot or dry patch on heater surfaces, justifying the expression of "self-rewetting" behavior. Self-rewetting fluids have been proposed and investigated by the authors as new heat transfer fluids for advanced heat transfer devices, e.g. heat pipes or heat spreaders for terrestrial and space applications. One of the most advantages is the possibility to use wickless ultra-light heat pipes in microgravity conditions. Experiments have been carried out in normal gravity and in low-gravity conditions with grooved and wickless heat pipes, thin flat heat pipes for thermal management in electronic devices, and flexible, inflatable and deployable radiator panels for space applications. These experiments have demonstrated that heat pipes filled with self-rewetting fluids exhibit, in general, better thermal performances in comparison with water heat pipes. Current developments are focused on self-rewetting brines and nanofluids, studied as candidate potential heat transfer fluids for space applications. Activities are in progress to perform experiments in space with a small technological payload onboard a microsatellite developed by the Italian Space Agency. After a general introduction on the subject, the paper summarizes the main activities in preparation of the microgravity experiment, the general design of the flight hardware and the experimental procedure planned for the flight. Numerical simulations are presented to illustrate the role of the surface tension gradient during phase change under microgravity conditions. The results are obtained with computational fluid dynamics simulations of the multiphase flow, based on the Volume of Fluid model, in presence of phase change. The laboratory results achieved on ground, including physical properties measurements are presented. The activities include laboratory measurements of surface tensions, carried out for a number of multicomponent solutions, including brines and self-rewetting nanofluids, to identify the most promising heat transfer fluids. In particular, surface tension measurements have been carried out with the pendant drop technique; the thermal conductivity has been measured with a steady state technique using thin foil heat flow meters on the upper and lower plates at the boundaries of a thin horizontal liquid layer heated from above. One of the most interesting results is that a positive surface tension dependence with temperature was found also in brines and nanofluids with small concentrations of butanol or heptanol. A number of figures of merit are introduced and evaluated on the basis of several fluids properties, including surface tension, contact angle, viscosity, freezing point, thermal conductivity, etc. The paper discussed the results of these investigations, and the characterization tests conducted on different heat pipes including reference ordinary heat pipes and several innovative pipes filled with self-rewetting fluids, brines and nanofluids.