Evaporation Induced Convection Under a Gas Channel

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Abstract

This work falls into a general framework which consists of observing the behavior of patterns and structures that can be formed after instability onset in an evaporating liquid layer. In previous work, we studied theoretical instability thresholds in pure fluids and in binary mixtures. What is of interest here, is a three-dimensional numerical simulation study of the transient temperature and fluid motion in the liquid evaporating into a nitrogen gas flow. The liquid is HFE7100 (an electronic liquid produced by 3M). The numerical (CFD) simulations are performed using the software COMSOL Multiphysics® (finite elements method).

The evaporation causes the instability and the gas flow evacuates the liquid vapor. The gas flow is maintained at 100 ml/min in a channel of 3 mm height, while three different liquid thicknesses are considered: 2, 4 and 8 mm. The width of the whole setup is 50 mm. The cover between the liquid and gas channel is 200µm thick. At the middle of this cover, there is an opening with a width of 10.6 mm, allowing contact between the liquid and gas channel. The boundaries of the whole system are kept at an ambient temperature and pressure of respectively 298 K and 1 atm, except for the gas channel outlet where only the ambient pressure is respected. Also, the whole system is surrounded by walls except for the gas flow inlet and outlet. The interface is kept at a constant height, since in the ESA experimental setup (on which this simulation is based) the liquid is to be replenished at the same rate as the evaporation rate. At the interface, Flux conservation is maintained and a tangential stress balance is considered. Furthermore, a no-slip condition is assumed at the interface.

The assumption of local thermodynamic equilibrium at the interface allows using Raoult's law, being temperature dependent via the Clausius-Clapeyron relation. The results show that first several small rolls are formed near the surface, caused by the surface-tension effect. Due to buoyancy and as time proceeds, the rolls grow towards the bottom of the liquid layer. Then the rolls also grow in horizontal direction merging with each other until a steady configuration is obtained. A relation or non-relation between the patterns at the interface and the evaporation rate is investigated. This work yields valuable information about the supercritical instability behavior of an evaporating liquid by means of fluid dynamics. Fig. 1 shows an example of the patterns observed.

Figures used in the abstract

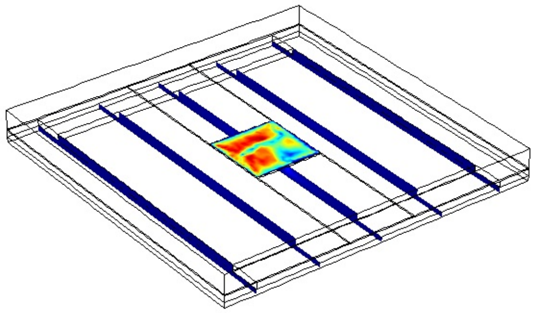

Figure 1: Example of velocity patterns caused by evaporation-induced thermal Rayleigh and Marangoni mechanisms