

Marangoni Flow Transition of Evaporating Liquid Layer in Enclosed Cylindrical Cell

Wen-Jun Liu^{1,4}, Paul G. Chen², Jalil Ouazzani³, Qiu-Sheng Liu^{1,4*} and Jun Qin^{1,2}

¹ Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

² Aix Marseille University, CNRS, Centrale Marseille, M2P2, Marseille, France

³ Arcofluid Consulting LLC, 309 N Orange Ave, Orlando, FL 32801, USA

⁴ University of Chinese Academy of Sciences, Beijing 100049, China

*liu@imech.ac.cn

Motivated by recent ground-based and microgravity experiments investigating the interfacial dynamics of a volatile liquid (FC-72, $Pr=12.34$) contained in a heated cylindrical cell and surrounded by a passive gas, we numerically study the thermocapillary-driven flow in such an evaporating liquid layer. Particular attention is given to the prediction of the transition of the axisymmetric flow to fully three-dimensional patterns when the applied temperature increases. The numerical simulations rely on an improved one-sided model [1, 2] of evaporation that includes the effect of conductive heat transport through the gas phase and the effect of the latent heat associated with a phase change at the interface. These effects are described by the heat transfer Biot number (Bi) and the evaporative Biot number (B_{ev}), respectively. For a sufficiently small Marangoni number, the flow remains steady and axisymmetric (see Fig 1), which is predominantly driven by thermocapillarity and slightly modified by buoyancy effects (in 1g). Due to a larger value of B_{ev} relative to Bi , the evaporative cooling effect significantly enhances the thermocapillary flow. When the Marangoni number is larger than a certain threshold the basic flow undergoes a transition to a fully 3D, steady-state flow. The numerical results show that the critical Marangoni number Ma_c decreases with increasing Biot number Bi , following a power-law (i.e., $Ma_c \sim Bi^{-2/3}$) in the absence of evaporation. Including evaporation leads to a saturation regime wherein Ma_c remains almost unchanged, giving thus a lower bound of the critical Marangoni number (≈ 120). Hence, both the conductive heat flux through the gas phase and the evaporative cooling play a destabilizing role, while buoyancy in the liquid layer has a stabilizing effect, though its effect is insignificant. Evaporation-induced destabilizing is due to the amplified thermal gradient in the radial direction (near the sidewall). The numerical results also show that evaporation stabilizes the flow by removing heat from the interface, resulting in a lower interfacial temperature in the central region of the liquid layer. There is a certain amount of competition between stabilizing and destabilizing role played by evaporation. The present work helps to gain a better understanding of the role of a phase change in the thermocapillary instability of an evaporating liquid layer.

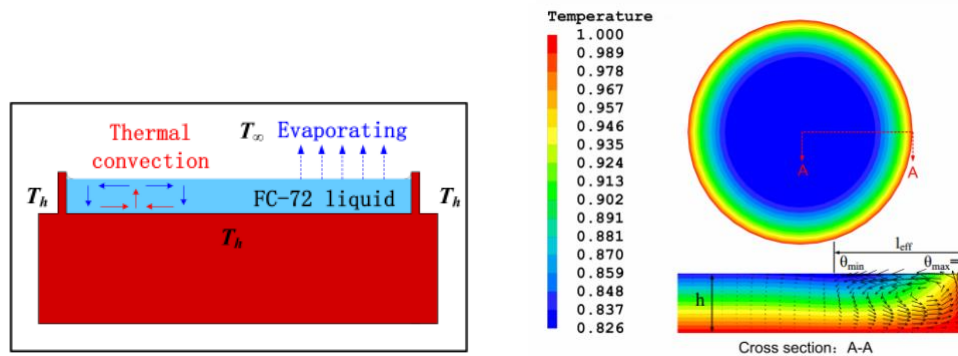


FIG. 1. Left: Schematic depiction of the experimental setup; Right: Surface temperature field (top), temperature and velocity fields (bottom) on the cross-section of axisymmetric flow.

ACKNOWLEDGEMENTS : This research was financially supported by the National Natural Science Foundation of China (Grants Nos. 11532015, U1738119), the China's Manned Space Program (TZ-1) and China Scholarship Council (CSC).

[1] F. Doumenc, T. Boeck, B. Guerrier, M. Rossi, Transient Rayleigh-Bénard-Marangoni convection due to evaporation: a linear non-normal stability analysis, *Journal of Fluid Mechanics* 648 (2010) 521–539.

[2] O. Ozen, R. Narayanan, The physics of evaporative and convective instabilities in bilayer systems: Linear theory, *Physics of Fluids* 16 (12) (2004) 4644–4652.