Evaporation Induced Convection Under a Gas Channel

Hatim Machrafi[1], Alexey Rednikov[2], Pierre Colinet[2], Pierre C. Dauby[1]
1. ULg, Thermodynamics of Irreversible Phenomena, Allée du Six-Août, 17, Liège 4000, Belgium;
2. ULB, TIPs-Fluid Physics, CP165/67, Avenue F.D. Roosevelt, 50, Brussels 1050, Belgium.

Introduction: This work falls into a general framework for space applications which consists of observing the behavior of patterns and structures that can be formed after instability onset in an evaporating liquid layer. What is of interest here, is a three-dimensional numerical simulation study of the transient temperature and fluid motion in liquid, used for electronic device cooling, (HFE7100) evaporating into a nitrogen gas flow. The physics are given in [1].

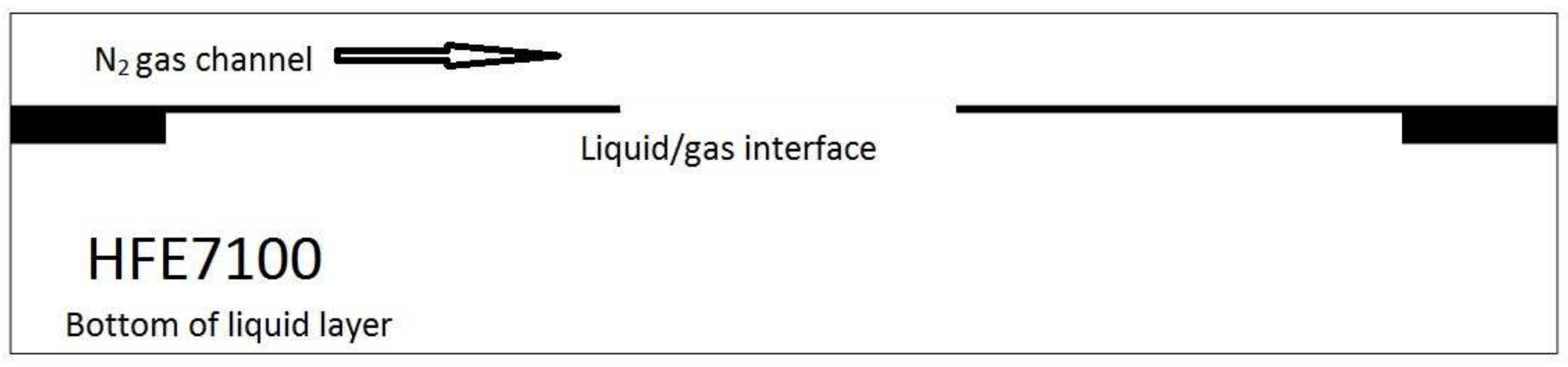

Figure 1. Front view of the setup

Computational Methods: We use the CFD and Heat Transfer Interfaces in both the liquid and gas phases. The most important physical and thermal processes take place at the liquid-gas interface. Local thermodynamic equilibrium is assumed at the interface, with a continuity of temperature and conservation of energy. Volume forces (Rayleigh mechanism) are considered in the liquid and Marangoni stresses at the interface. For this, the force density and the tangential stress balances are given respectively by:

$$f = \rho_{ref}\left(1 - \alpha_T\left(T - T_{ref}\right)\right)\vec{g}\vec{1}_z$$

$$-\mu_g\left(\frac{\partial w_g}{\partial x} + \frac{\partial u_g}{\partial z}\right) + \mu_l\left(\frac{\partial w_l}{\partial x} + \frac{\partial u_l}{\partial z}\right) + \gamma_T\frac{\partial T}{\partial x}$$

$$-\mu_g\left(\frac{\partial w_g}{\partial y} + \frac{\partial v_g}{\partial z}\right) + \mu_l\left(\frac{\partial w_l}{\partial y} + \frac{\partial v_l}{\partial z}\right) + \gamma_T\frac{\partial T}{\partial y}$$

Results: First we show the intrinsically different patterns caused by volume forces in the liquid at 1 and 10 seconds after evaporation sets in. Then we show the patterns at the interface for different times (0.1, 1, 2 and 10 seconds). Finally we present the evaporation rate. In Figures 2, 3 and 4, the liquid thickness is 2 mm, the gas channel is 3 mm high and the gas flow is 100 ml/min. The evaporation rate will also be given for different gas flow rates.

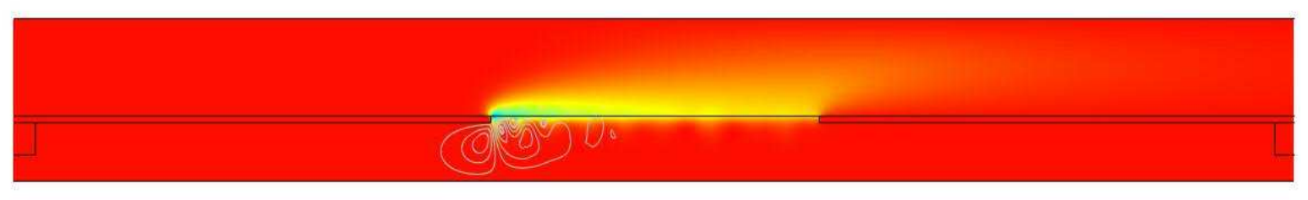

Figure 2. Front view of gravity driven patterns at 1 s

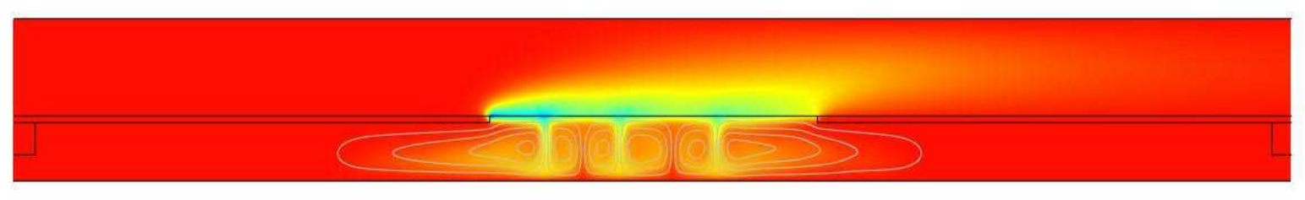

Figure 3. Front view of gravity driven patterns at 10 s

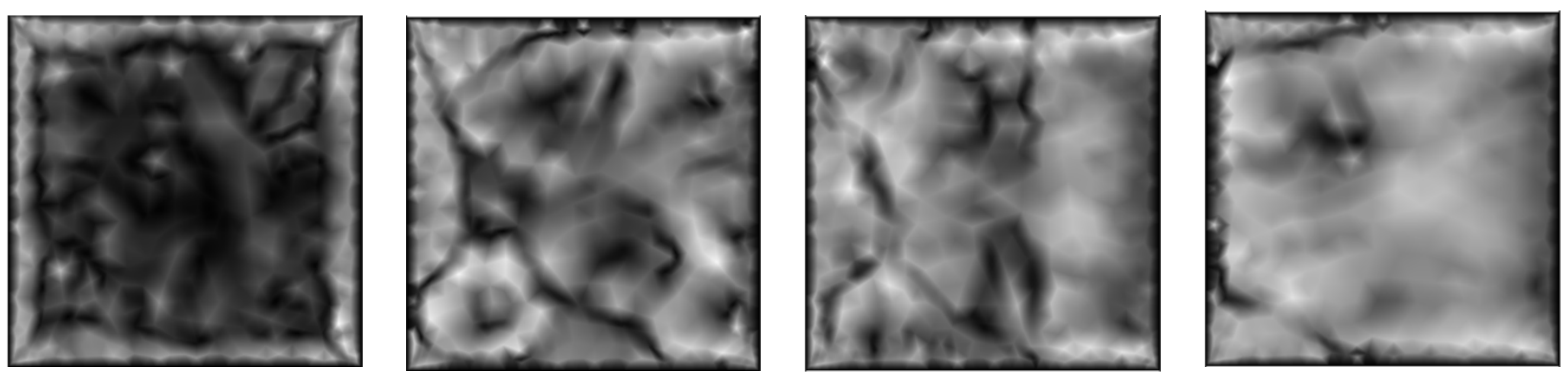

Figure 4. Upper view of the liquid-gas interface at times 0.1, 1, 2 and 10 s, respectively

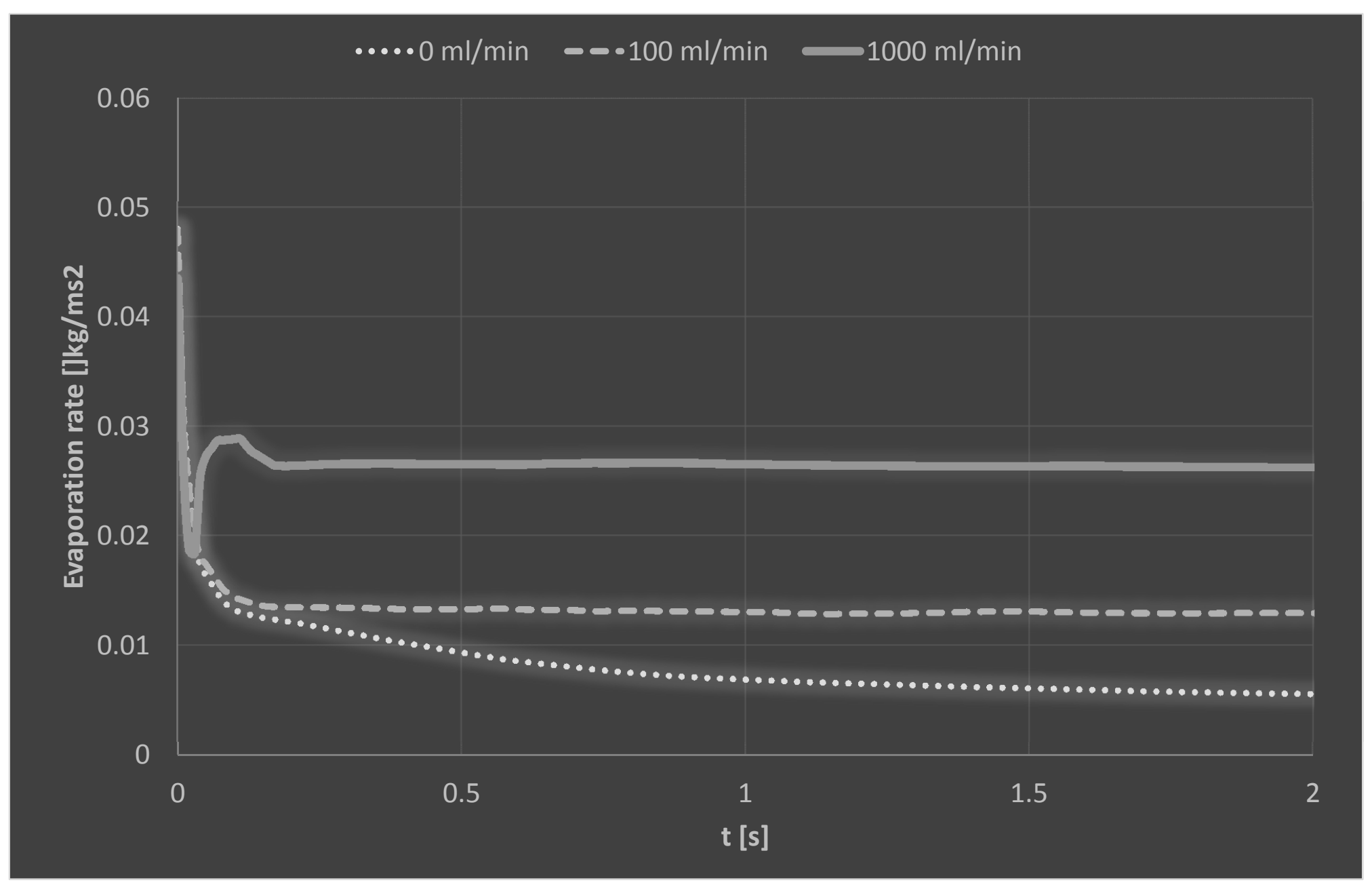

Figure 5. Evaporation rate as a function of time, for different gas flow rates

Conclusions: 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. At first, the developing patterns influence the evaporation rate, but the evaporation rate reaches a quasi-constant value, as soon as chaotic patterns are observed. The same goes for other gas flow rates.

References:

1. H. Machrafi, A. Rednikov, P. Colinet, P.C. Dauby, Time-dependent Marangoni-Bénard instability of an evaporating binary-liquid layer including gas transients, Physics of Fluids 25, 084106 (2013)

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