

# Extremely Unstable Evaporative Bénard-Marangoni Systems: the Role of Transients in the Gas

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The present theoretical study is concerned with Bénard-Marangoni instabilities in horizontal liquid layers evaporating into the air, when possible extrinsic horizontal non-uniformities in the system are not essential. The vertical temperature gradients responsible for the instability here owe themselves entirely to the cooling occurring at the liquid-gas interface due to the latent heat of evaporation. In the case of a binary liquid, solutal gradients appear too in view of different volatility of the components. The solutal mechanisms of instability, for non-pure liquids, actually have a certain tendency to be predominant over the thermal ones as far as instability thresholds are concerned, or at least this is so in the examples considered here. The evaporation rate in the base state is determined by an effective transfer distance in the gas phase (typically, 1 mm ÷ 1 cm), at which the ambient conditions for the pressure, temperature and humidity are specified, and which appears in the model as an effective thickness of the gas layer [1]. Even though still a semi-empirical parameter, the transfer distance allows for a more precise and versatile description than merely the transfer coefficients often used in the literature, for it permits to explore a possible active role of the gas phase.

The feature we mainly focus upon in this presentation is the critical layer thickness for the onset of monotonic instability. The critical thickness turns out to be typically so small, well into a sub-millimeter range, that it is only the Marangoni mechanism (the thermal one for pure liquids, and the solutal one for binary mixtures) that is relevant in this context, the Rayleigh/buoyancy contributions being negligible. Furthermore, we focus our attention upon non-longwave modes of instability, for which the interface can be considered as undeformable, even for very small thicknesses, thanks to the action of the Laplace pressure (small capillary number). The role of the gas layer in the problem for perturbations proves to be well accountable for by means of a Biot number in the framework of a one-layer formulation, albeit this Biot number is here a function of the wavenumber of perturbations, which is a manifestation of the mentioned “activity” of the gas phase. All in all, the analysis we deal with can essentially be characterized as Pearson-like in a broad sense of the word.

Now the specific goal of the present study is to demonstrate that, under otherwise equal conditions, the critical thicknesses for transient regimes can actually be appreciably lower than those known for the corresponding (quasi-)stationary base states (towards which these transients evolve). Here we consider the transients resulting from initially putting in contact uniform (without temperature and composition gradients) liquid and gas phases that are not in phase equilibrium with each other so that evaporation and transient temperature and concentration profiles ensue. The key to this effect is that the system be sufficiently unstable (“extremely unstable”), with a sufficiently high Marangoni factor, so that the instability occurs well before a (quasi-)stationary state gets established in the effective gas layer. In fact, it turns out that systems with sufficiently volatile liquids (such as HFE-7100, or even ethanol, at normal conditions) or with binary mixtures possessing a strong solutal Marangoni factor (e.g. ethanol in water [2]) prove all to be extremely unstable in this sense, implying of course that the ambient relative humidity is well below 100%. The analysis for the transients is carried out using the frozen-time approach.

[1] Haut, B. and Colinet, P., *J. Colloid Interface Sci.*, **285**, pp. 296-305, 2005.

[2] Machrafi, H., Rednikov, A., Colinet, P. and Dauby, P.C., *J. Colloid Interface Sci.*, **349**, pp. 331-353, 2010.