

# Characterising Instabilities in Evaporating Pools and Sessile Droplets

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## Abstract

This talk will discuss detailed evolution of thermocapillary instabilities (leading to hydrothermal waves) during evaporation of liquids under three geometrical configurations of pure fluids: i) planar pools ii) hemispherical sessile droplets and iii) non-hemispherical sessile droplets. The results presented are obtained via 3D, two-phase direct numerical simulations (DNS) that are validated rigorously against experiments and theory.

*Evaporating planar pools:* Here the effects of phase change on the stability of a laterally-heated liquid layer are investigated. The interface is open to the atmosphere and vapour diffusion is the rate-limiting mechanism for evaporation. As discussed above, this configuration is naturally vulnerable to the formation of the so-called hydrothermal waves (HTWs) and interfacial waves. Our DNS studies reveal that phase change plays a dual role through its effect on these instabilities: the latent energy required during the evaporation process tends to inhibit the HTWs while the accompanying level reduction enhances the interfacial waves by minimizing the role of gravity. The Marangoni effect plays a major role in the vapour distribution generating a vacuum effect in the warm region and vapour accumulations at the cold boundary capable of inverting the phase change, i.e. the capillary flow can lead to local condensation. This work also demonstrates the inability of the traditional phase change models based on pure vapour diffusion to capture the dynamics of thermocapillary flows.

*Evaporating hemispherical sessile droplets:* A novel 3D two-phase model based on the diffuse-interface method is developed to investigate the fully-coupled two-phase dynamics of a sessile drop undergoing evaporation on a heated substrate. General transient advection-diffusion transport equations are implemented to address the conservation of energy and vapour in the gas phase, which also allows the more realistic modelling of interface mass and energy transport based on local conditions. Both constant-angle (CA) and constant-radius (CR) modes of pure evaporation are successfully simulated and validated against experiments. The emphasis of this investigation is on addressing three-dimensional phenomena during evaporation of drops with non-circular contact area. Irregular drops lead to complex interface shapes with intricate contact-angle distributions along the triple line and with a three-dimensional flow which previous axisymmetric approaches cannot show. The versatility of this model also allows the simulation of the more complex case of drops evaporating with a moving contact line.

*Evaporating non-hemispherical sessile droplets:* The spontaneous development of 3D azimuthal vortices parallel to the plane of substrate in a non-hemispherical evaporating drop of water with irregular contact area is reported by means of experiments and direct numerical simulations (DNS). In spherical droplets, the non-uniform evaporation flux leads to a 2D axisymmetric flow with fluid being transported along the interface from the contact line (hotter) towards the apex (colder) due to the Marangoni effect. Infrared recordings of a non-spherical drop show the break of symmetry and the consequent development of a preferential direction for thermocapillary convection. As a result, counter-rotating whirling currents emerge in the drop playing a critical role in regulating the interface thermal motion. This geometry-induced phenomenon is also investigated via simulations with a fully-coupled two-phase model. DNS show good agreement with experiments and reveal the intricate drop dynamics due to this geometry-induced phenomenon. The triggering mechanism is analysed along with the resulting bulk flow.

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