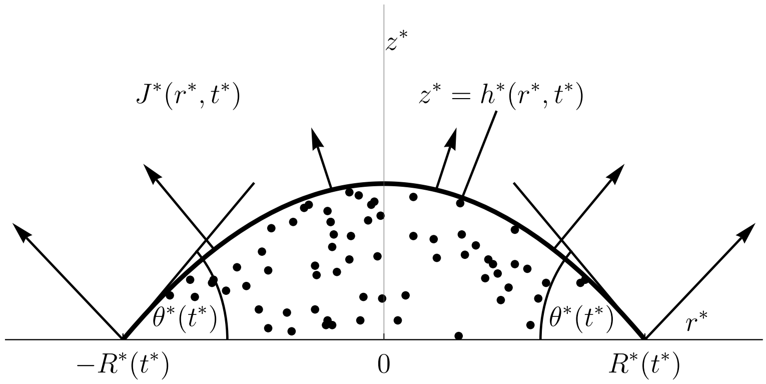
Particle deposition from a unpinned, particle-laden, sessile droplet undergoing one-sided evaporation

Henry T. Sharp[*], Stephen K. Wilson[†*], Alexander W. Wray[*]

The evaporation of a sessile droplet is a widely studied phenomenon due to its variety of industrial applications, including inkjet printing[1] and the production of biomarkers[2]. In these applications, droplets contain suspended particles, and the morphology of particle deposition on the substrate is of considerable interest. In the case of inkjet printing for example, a uniform deposition of particles is typically required to produce a high-quality image[3]. The evaporation-induced flow within the droplet determines the morphology of the final deposit of particles on the substrate after the droplet has entirely evaporated. When an evaporating droplet is surrounded entirely by vapour, or when the vapour moves rapidly away from the surface of the droplet, the liquid and gas phases decouple, and evaporation is entirely dependent on the liquid phase[4]. In this case, the associated departure from thermodynamic equilibrium at the liquid-gas interface is what drives evaporation and is described by the so-called "one-sided" model of evaporation [5]. This is in direct contrast with the more common case of diffusion-limited evaporation in which the liquid and gas phases are coupled and, in particular, the evaporation depends on the transport of vapour in the gas phase[6]. A model predicting the concentration and mass of suspended particles within an unpinned, thin, particle-laden, axisymmetric, sessile droplet undergoing one-sided evaporation is formulated and analysed. It is shown that for such a droplet, the final deposition of particles is strongly dependent on the degree of departure from thermodynamic equilibrium at the liquid-gas interface. This is because the radial volume flux that advects particles is determined by a combination of an outward capillary flow and an inward flow driven by the receding contact line, which both depend on the degree of departure from thermodynamic equilibrium. In particular, unlike for a droplet with a pinned contact line, the flow within an unpinned droplet can be simultaneously inwards towards the centre of the droplet and outwards towards the contact line. The combination of these competing effects result in a particle distribution across the initial footprint of the droplet that is much closer to uniform than seen in diffusion-limited and/or pinned cases.



Sketch of a thin, particle-laden, axisymmetric, sessile droplet undergoing one-sided evaporation with contact radius $R^*(t^*)$, contact angle $\theta^*(t^*)$ and free surface $z^* = h^*(r^*, t^*)$. The arrows indicate the local evaporative mass flux $J^*(r^*, t^*)$.

[*]Department of Mathematics and Statistics, University of Strathclyde, Livingstone Tower, 26 Richmond Street, Glasgow, G1 1XH, United Kingdom
[†]Department of Mathematical Sciences, University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom
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