Liquid film dynamics in pulsating heat pipes
Xiaolong Zhang

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Pulsating heat pipe (PHP, Caloduc Oscillant in French)

- Promising, high-efficient, passive heat transfer devices, particularly in thermal control systems for aerospace applications.
- A capillary meandering between evaporators (heat sources) and condensers (heat sinks), with optional adiabatic sections.
- Partially filled with working fluid: vapor bubbles and liquid plugs.
- Self-sustained oscillation of liquid plugs as a result of pressure imbalance among the CASHBUBBLEs.
- Liquid films are deposited by receding plugs.

**Motivation**

- Liquid film dynamics is crucial, because heat exchange through the films is its dominant mechanism.

**Film profile with pinned contact line and oscillating meniscus, under adiabatic condition**

1. Comparison to experiments of Liu et al. (2010)
   - An oscillating liquid plug in a cylindrical capillary tube.
   - When the meniscus advances, a plug and a condenser (C). Inside the tube a bubble, a meniscus (film) and a plug.

2. Contact angle variation
   - Variation of θ is periodic, because θ is imposed by the film shape (controlled by the meniscus).
   - The initial θ is the maximum value achieved during oscillation: minimum nearly constant for a large part of a period, because the meniscus is away from the contact line.

3. Contact line recession
   - Minimal contact angle decreases with ΔT, which implies that it will reach zero for a certain ΔT. For larger ΔT, the solution does not exist.
   - CAm monotonically increases with ΔT, which is more significant than that on θ, which signifies that the evaporation effect prevails.

The Lubrication Approximation and Kelvin Effect

- Curvatures are replaced by the model lumped shape.
- Film deposition by the receding meniscus is a function of meniscus speed (from film dynamics).
- Contact line recession is uniform, but evolves with time. Results will be compared to experimental data.

**Film profile with pinned contact line, oscillating meniscus and tube wall heating ΔT**

1. Contact angle variation
   - Contact line receding because the ripples approach back, a minimal value appears.

2. Contact line recession
   - Minimal contact angle decreases with ΔT, which implies that it will reach zero for a certain ΔT. For larger ΔT, the solution does not exist.

**Contact line motion: dewetting problem with substrate heating**

1. Film speed as a function of ΔT and #

At the end of a period

- Contact angle oscillates because the ripples of the film
- A minimal value appears.

**Contradiction between experiments and calculations**

- At a minimal value appears.

**Film dynamics with pinned contact line and meniscus oscillation**

- The lubrication approximation and Kelvin effect.
- Local contact angle θ and meniscus curvature CA are oscillating.
- Meniscus velocity U is slow; shape determined by surface tension (hemi-spherical).
- Films: mostly flat and thin (~100 μm), low Re number and strong viscous forces.

**Contact line motion: dewetting problem**

- Contact line recession because of capillary action and liquid evaporation.
- Dewetting ridge forms by collecting the liquid.