Microscale Heat Transfer and Fluid Flow in an Evaporating Moving Extended Meniscus

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Prepared for presentation at AIChE 2005 Annual Meeting, Cincinnati, OH.

Extended Abstract

Due to the large ratio of interfacial area to system volume, interfacial forces can have a controlling effect on phase change processes in microscale systems. For example, the interfacial pressure jump gradient due to varying disjoining and capillary pressures is used extensively for fluid control and stability in passive heat pipes with and without wicks [Potash and Wayner, 1972]. To optimize the design and use of microscale systems, experimental data on the microscopic details of phase change heat transfer, fluid flow, and stability in an extended meniscus are needed. Herein, the results of experiments on an evaporating extended meniscus of pure pentane on a quartz surface in a constrained vapor bubble (heat exchanger) are presented.

The evaporative heat flux distribution in the leading edge region of a moving evaporating thin liquid film of pentane on quartz was obtained by analyzing the measured thickness profile for thicknesses, $\delta < 2\ \mu m$. The profiles in a constrained vapor bubble were obtained using image analyzing interferometry. Although the evaporating meniscus appeared to be benign, high heat fluxes were obtained. Significantly higher heat fluxes are possible. The interfacial slope, curvature, interfacial shear stress, and liquid pressure profiles were also obtained. The results obtained, using a continuum model, were consistent with those obtained using a control volume model. The measured pressure field profile of the isothermal extended meniscus agreed with the constant pressure field predicted by the augmented Young-Laplace model. For the nonisothermal case, measured thickness gradients lead to disjoining pressure and curvature gradients for fluid flow and evaporation. The experimental results confirm that disjoining pressure at the contact line controls fluid flow within an evaporating completely wetting thin curved film and is, therefore, a useful boundary condition [Panchamgam et al., 2005a]. However, in small interfacial systems, non-idealities can have a dramatic effect.

Experimental System

In the experimental system, liquid from the pool at the bottom of the cuvette rises along the corners of the cuvette due to capillary and disjoining pressure forces and thereby forms a continuous extended meniscus in the four corners of the cuvette (see Fig. 1). Also, it forms extended menisci at the top end of the cuvette. To study the fluid flow and

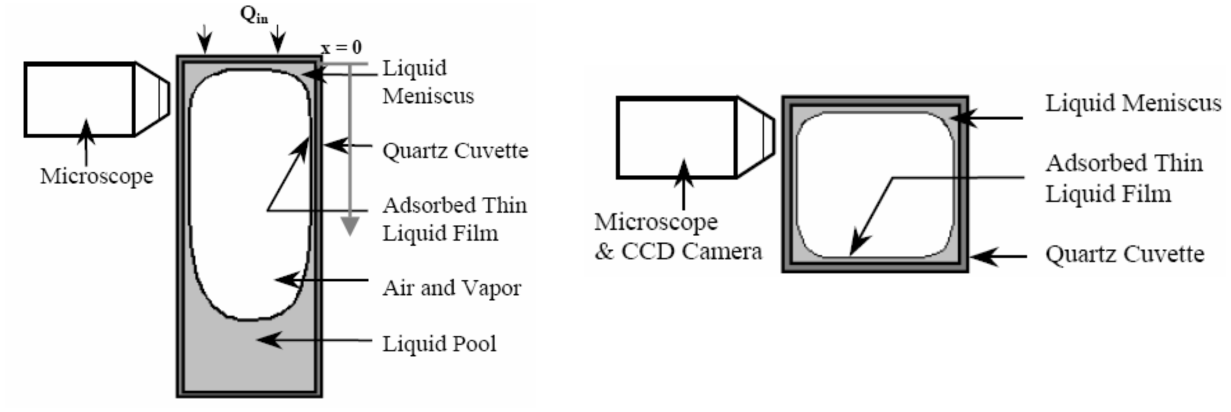

Figure 1. Schematic diagram of the experimental setup, (left) vertical cross-sectional view of the quartz cuvette (inside dimensions 3 mm × 43 mm), and (right) horizontal cross-sectional view with inside dimensions 3 mm × 3 mm. Gravity g is acting perpendicular to the cross-section.

evaporation, we changed the heater power from isothermal (reference state) to $Q_{in} = 0.076$ W. The resulting movement of the meniscus due to evaporation was captured and analyzed. Initially, the pentane meniscus receded toward the corner of the cuvette (transient state), followed by a slow advancement and pseudo-steady states.

Monochromatic light ($\lambda = 546$ nm) from a mercury light source was used to illuminate the cuvette through the objective of the microscope. Naturally occurring interference fringes appeared (see Fig. 2), which were due to the reflection of light from the liquid-vapor and the liquid-solid interfaces. A CCD camera with a maximum frame rate of 30 frames per second was used to capture interference images of the receding and advancing menisci. The captured images were digitized using a data acquisition card (DT3155- MACH Series Frame Grabber).

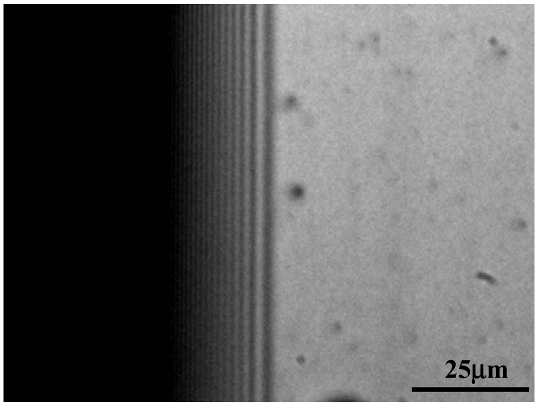

Figure 2. Fringe pattern of a non-equilibrium extended corner meniscus of pentane at $x \approx 0$ ($Q_{in} = 0.076$ W).

The conclusions from the complete paper [Panchamgam et al., 2005b]

- A procedure to measure the heat flux distribution for the film thickness region, $\delta < 2$ μm in an extended meniscus was developed.

- Results obtained, using a control volume model, were found to be consistent with those obtained using a continuum model.

- The results demonstrate that the disjoining pressure controls the fluid flow within an evaporating completely wetting thin curved film.

- The measured pressure field in the isothermal extended meniscus agreed with the augmented Young-Laplace equation.

Acknowledgments

This material is based on the work supported by the National Aeronautics and Space Administration under grant number NNC05GA27G. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of NASA.

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