Free surface profile of evaporative liquids at the vicinity of the contact line

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ABSTRACT

Interfacial phenomenon, specifically those associated with evaporation from thin liquid films near the contact line of a liquid drop, play a major role in many current engineering applications which require high local heat fluxes, as evident in heat pipes, grooved evaporators, fuel cells and suction nucleate boiling devices. [3]. This study will prove useful in the improvement of such applications. Fluoresces microscopy was used as our main technique of investigating the free surface profiles of evaporative liquids, as it delivers sufficient range and resolution to address the challenge of capturing the microscopic and macroscopic aspects of this phenomenon.

THEORETICAL EXPECTATION

The dynamics of the contact line has been studied for decades with much work devoted to its fundamental understanding. Here we only consider the case of complete wetting where a precursor film develops and spreads ahead of the contact line. The situation under study is shown in the figure below [2].

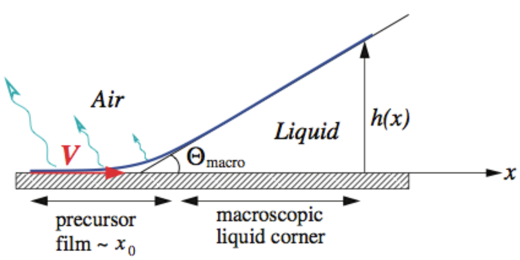

Figure 1: Problem Schematic Structure, detailing the microscopic region where evaporation occurs and microscopic region, and problem annotations from [2]

The free surface velocity moves at a constant velocity V under the effect of fluid motion U due to pressure gradient, and evaporation flux J. the problem is solved using standard lubrication theory in the limit of low Reynolds numbers and small interference slope along with a divergent evaporation field and viscous stress at the contact line [2]. This results in the following non-dimensional liquid thickness H, as a function of the non-dimensional distance X as shown by the figure below [2].

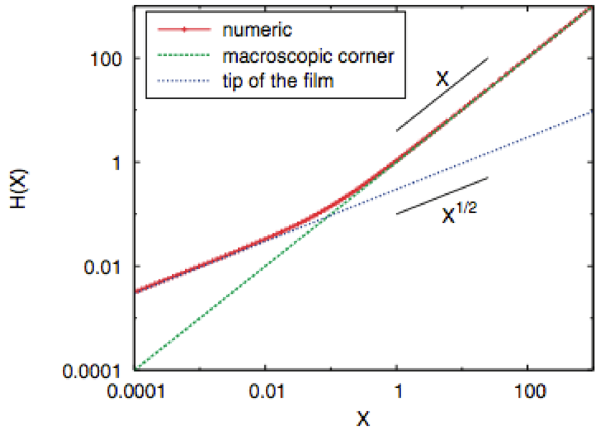

Figure 2: Comparison between theoretical forms of profiles from [2]

Where

$$X = x/x_0 \qquad , \qquad H = h/h_0$$

And

$$h_0 = x_0^{\frac{1}{2}}\left(\frac{\mathcal{A}}{2\pi\gamma}\right)^{\frac{1}{4}} \qquad , \qquad x_0 = \left(\frac{|\mathcal{A}|}{12\pi J_0\eta}\right)^{\frac{2}{3}}$$

Where $\mathcal{A} = 10^{-19}\ kgm^2s^{-2}$ is the Hamaker constant, γ is the surface tension, η is the liquid viscosity. Two distinct scaling's are observed, a linear profile in the macroscopic region and parabolic region in the microscopic one [2].

EXPERIMENTAL TECHNIQUE

Fluorescence microscopy is used as an optical technique to investigate the free surface profiles of evaporative liquids. Current methods of measuring thin film thicknesses and profiles include polarized reflection microscopy, atomic force microscopy, ellipsometry and inferometry however these techniques provide poor spatial and temporal resolutions as compared to fluorescence microscopy. With Fluorescence microscopy, we are capable of measuring film thicknesses on the order of nanometers [1].

A fluorescent dye is first dissolved into low viscosity silicon oil. The microscope light is filtered to a range corresponding to the dye's excitation range, which illuminates the sample homogenously. The illuminated light is passed back through the objective lens, which is then analyzed and quantified. The camera captures the intensity of the emitted light from the sample, which through Beer-Lamberts law, is linearly proportional to the film profile thickness.

$$y = \propto I$$

Where y is the film thickness, ∝ is the proportionally constant and I is the emitted light intensity measured by the camera [1].

For our particular experiment, low viscosity silicon oil and a photochromic dye is dissolved. Upon excitation, the chemical species of the photochromic dyes change form such that the absorption band shifts in strength or wavelength. The photochromic dye is excited by ultra violet light and changes the solutions appearance from colorless to a violet color; the intensity of this violet color is then correlated to the film profile thickness. The image is captured using a 60x objective lens of a Nikon eclipse TE-2000S Microscope with an inverted configuration.

EXPERIMENT SETUP AND RESULTS

The experimental set up involves the low viscosity silicon oil between two glass substrates with the inverted microscope set up as shown in the figure below.

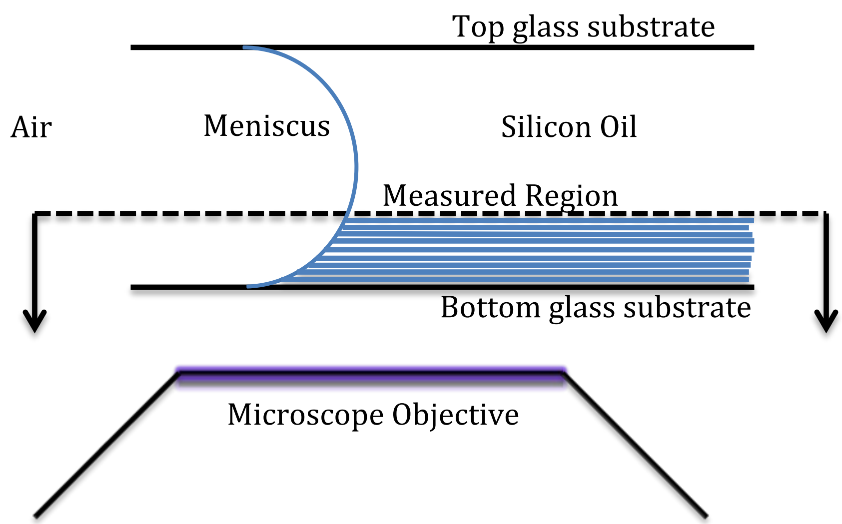

Figure 3: Experimental setup: inverted microscope configuration viewing silicon oil meniscus formed between two glass substrates

The two glass substrates result in a meniscus formation of the silicon oil. The 60x microscope objective has a measurable depth region, which is also shown in the figure above. Therefore the illuminated region is below the measurable depth and is shown by the blue shaded region in the figure above. A picture captured by the microscope is shown below, with the contact line clearly visible and located vertically in the middle.

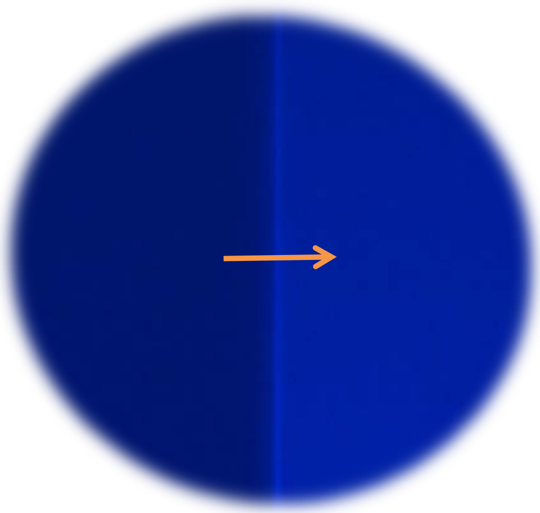

Figure 4: Microscope captured image of silicon oil meniscus contact line. The orange arrow indicates the region of interest of the intensity profile.

The intensity profile captured by the microscope is shown below, and is in the region dictated by the orange arrow in the figure above. This intensity profile will be calibrated through the proportionality constant described previously, which results in film thickness. However both will depict the same relative profile shape.

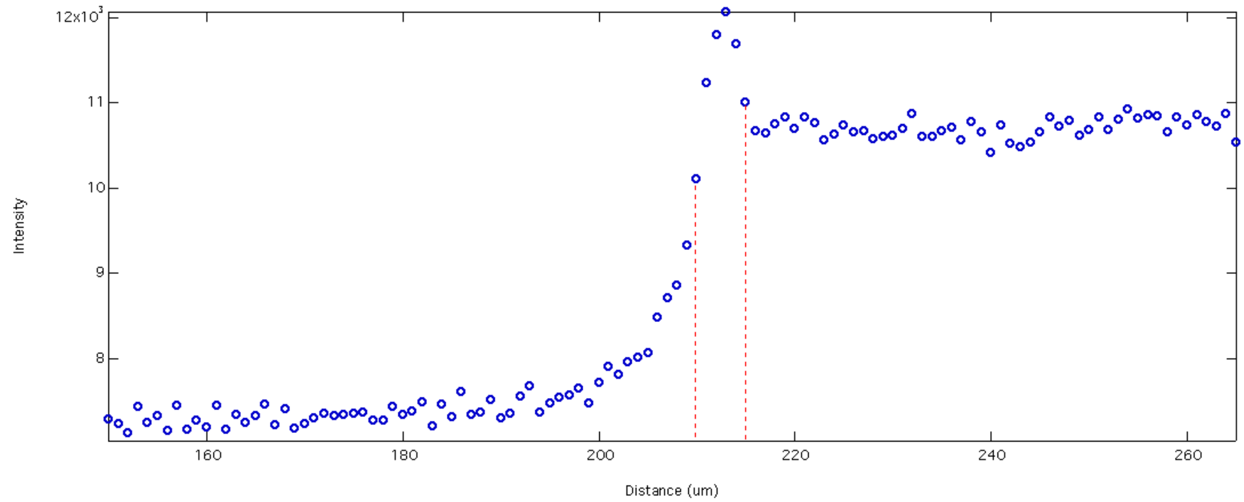

Figure 5: Experimental intensity profile results in the vicinity of the meniscus region of the silicon oil, the location of which is represented by the orange arrow in figure 4. The two red dashed vertical lines depict the start of the contact line (right) and the beginning of the meniscus region (left)

It is observed that the right most red, vertical, dashed line represents the start of the contact line while the left most red, vertical, dashed line represents the beginning of the meniscus region. The first region may indicate the start of a precursor region or could possibly indicate a reflection of light on the glass substrate due to the illuminated film.

References

1. Hoang, A., Kavehpour, P., (2012), “Dynamic Measurement of microfilms and nanofilms of fluids using fluorescence microscopy ”, Exp Fluids 52: 1657-1662.
2. Pham, C, T., Limat, L., (2010), “Dynamics of complete wetting liquid under evaporation” , EPL 92: 54005.
3. Potash, M., Wayner, P, C., (1971), “Evaporation from a two dimensional extended meniscus”, Int. J. Heat Mass Transfer, 15: 1851-1863