



A DISJOINING PRESSURE FOR SMALL CONTACT ANGLES AND ITS APPLICATIONS

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ABSTRACT

A thin liquid film experiences additional intermolecular forces when the film thickness h is less than roughly 100 nm. The effect of these intermolecular forces at the continuum level is captured by the disjoining pressure Π . Since Π dominates at small film thicknesses, it determines the stability and wettability of thin films. To leading order, a thin film can be treated as uniform and $\Pi = \Pi(h)$. This form, however, cannot be applied to films with non-zero contact angles. A recent ad-hoc derivation to include the slope h_x leads to a $\Pi = \Pi(h, h_x)$ that allows a contact line to move without slip [1, 2]. This work derives a new disjoining-pressure formula by minimizing the total energy of a drop on a solid substrate (Fig. 1). The minimization yields an equilibrium equation that relates Π to an excess interaction potential (Fig. 2), $E = E(h, h_x)$. By considering a fluid wedge on a solid substrate, $E(h, h_x)$ is found by pairwise summation of van der Waals potentials. This gives in the small-slope limit

$$\Pi = \pm \frac{B}{h^3} (\alpha^4 - h_x^4 + 2hh_x^2 h_{xx}),$$

where α is the contact angle and B is a material constant. The term containing the curvature h_{xx} is new; it prevents a contact line from moving without slip. For a uniform film, $h_x = h_{xx} = 0$, and $\Pi = \pm B\alpha^4/h^3$, which recovers the expression used previously [3, 4]. Equilibrium drop and meniscus profiles are calculated for different B , as shown in Figs. 3–6, where ε is the ratio of disjoining to capillary pressure. Evolution of a film step is solved by a finite-difference method with the new disjoining pressure included; it is found that $h_{xx} = 0$ at the contact line is sufficient to specify the contact angle (Fig. 7).

FIGURES AND TABLES

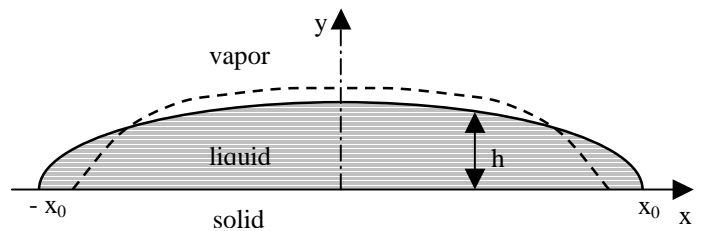


Figure 1. A two-dimensional drop on a solid substrate.

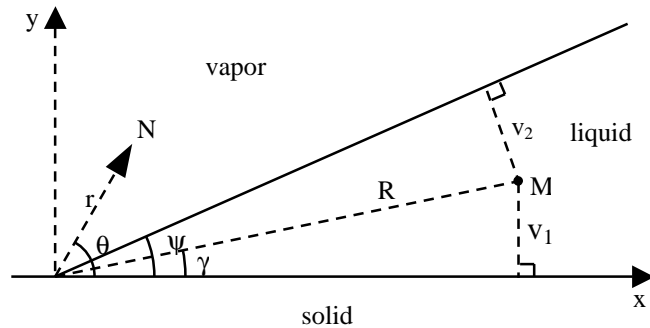


Figure 2. A liquid wedge on a solid substrate.

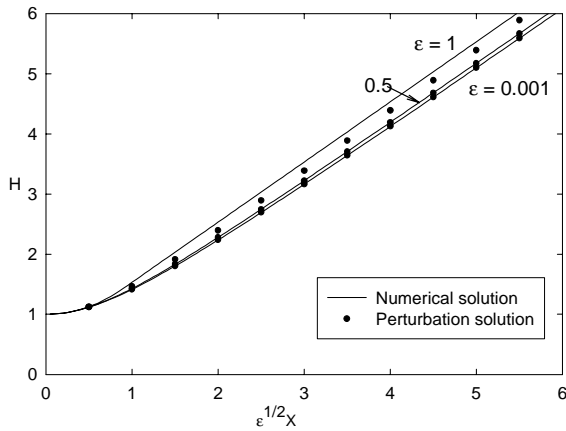


Figure 3. Equilibrium profiles of $C=0$ with symmetric central condition.

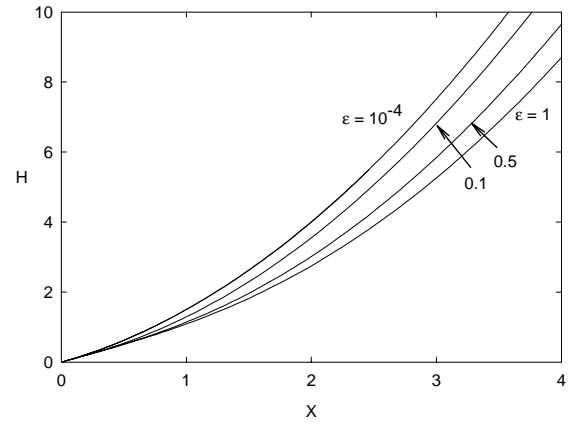


Figure 6. Contact film grows to a meniscus.

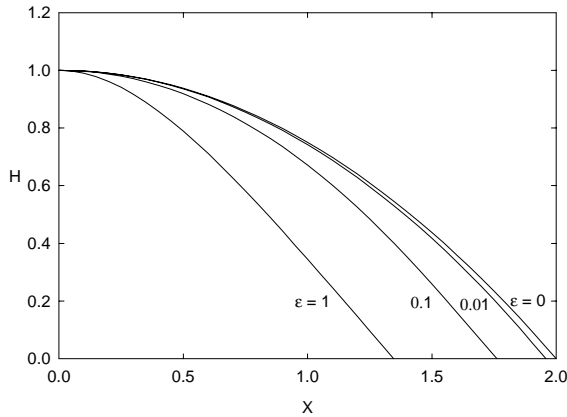


Figure 4. Equilibrium drop profiles.

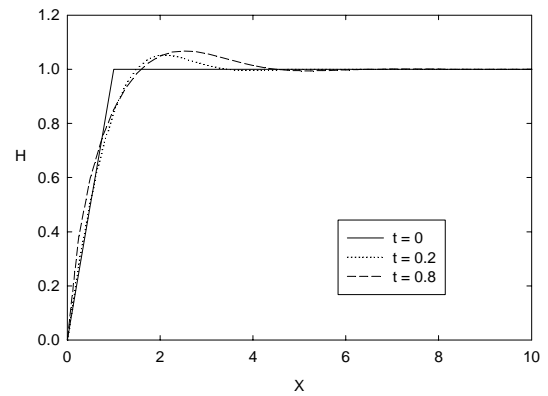


Figure 7. Evolution profiles of the step thin film with fixed contact line at different time.

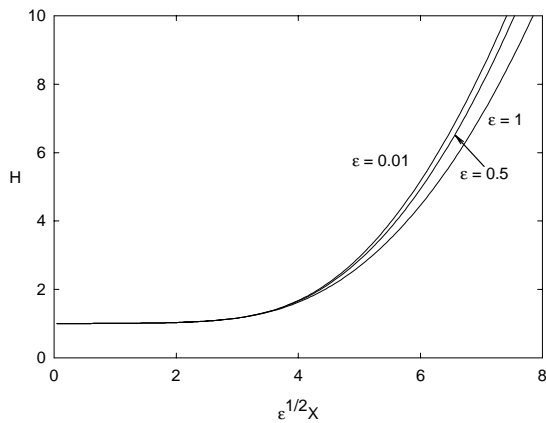


Figure 5. Uniform-film grows to a meniscus.

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4. E. K. Yeh, John Newman, and C. J. Radke, *Colloids and Surfaces A.* **156**, 525 (1999)