An Interferometric Study of Moving Contact Line Dynamics

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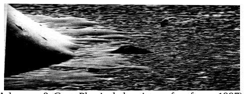
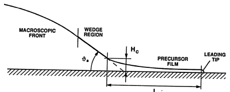
Spreading of Fluids and Precursor Layer

- Hardy (1919) reported the existence of a very thin film in front of moving wetting line.
- Cottington et al. (1964) used ellipsometry to observe precursor film.
- Hervet & de Gennes (1984) theory on 1-D thin spreading edge.
- Existence of large extrapolation length for velocity field of polymeric liquids near a smooth surface predicted by de Gennes (1985).
- Huppert (1982) and Goodwin & Homsy (1991) studies of gravity currents and spreading of viscous drops on inclined plates.

Project Goal: Develop a non-invasive optical technique that has sufficient spatial and temporal resolution to investigate contact line evolution.



(Adamson & Gast, Physical chemistry of surfaces, 1997)

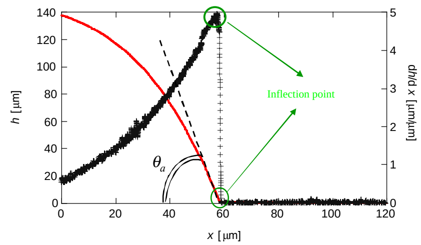


(Kistler, Hydrodynamics of wetting, 1993)

Dynamic Contact Angle, θ_a

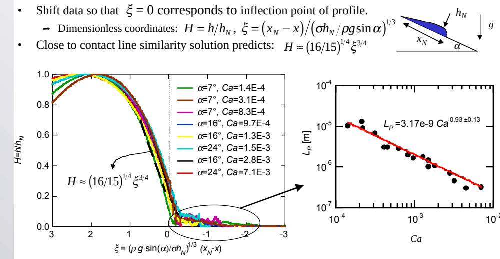
$$\theta_a = \tan^{-1}\left((dh/dx)_{max}\right)$$

- Local slope is calculated by numerical differentiation of drop profile.
- Dynamic contact angle, θ_a, corresponds to maximum value of slope.

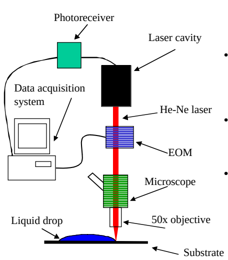


Gravity Current on an Inclined Plate

- Spreading of viscous drops on an inclined plate under gravitational body force.
- Measure droplet profile and and compare with self-similar profile predicted by Huppert (1982)
- Shift data so that $\xi = 0$ corresponds to inflection point of profile.
  - Dimensionless coordinates: $H = h/h_N$, $\xi = (x_N - x)/(\sigma h_N/\rho g \sin\alpha)^{1/3}$
- Close to contact line similarity solution predicts: $H \approx (16/15)^{1/4}\xi^{3/4}$



Phase-shifted Laser Feedback Interferometer(psLFI)



- Feedback into the laser eliminates the need for a beam splitter and separate reference arm.
- Electro-optical modulator (EOM) is used to impose a series of controlled phase changes.
- Vertical spatial resolution of 10 nm is achieved using phase-shifting algorithm.
- Diffraction-limited lateral resolution achieved using high N.A. objectives.

(Ovryn & Andrews, *Appl. Opt.*, 1999)

Confirmation of Tanner's Law

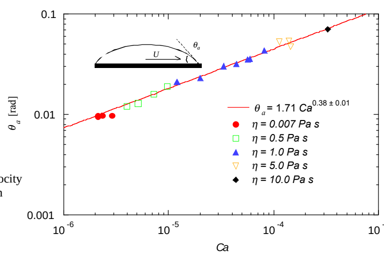
- Vary spreading velocity by using several different silicone oils.
- Dynamic contact angle is proportional to the capillary number, $Ca^{1/3}$. (Tanner, 1979)

For perfectly wetting fluids:

$$\theta_a \sim Ca^{1/3}$$

$$Ca = \frac{\eta U}{\sigma}$$

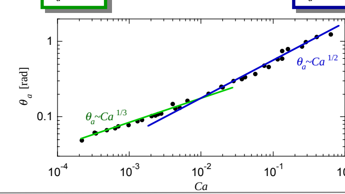
η : viscosity
U : Spreading velocity
σ : surface tension



Power-laws for Spreading Drops on Inclined Plates

- For small inclination angles($\alpha \to 0$), lubrication theory remains valid.
- For $\alpha \to 0$ and for $Ca \ll 1$ Tanner's law recovered:
- On "steeply inclined" plates, lubrication theory is not valid, $Bo \sim O(1)$ (Goodwin & Homsy, 1991; Hocking, 1983).
- Spreading is driven by a quasi-steady static balance, hence: $Ca \equiv Bo = \rho g h^2 \sin\alpha/\sigma$

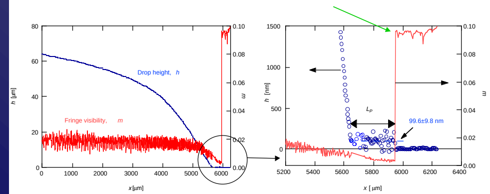
$\theta_a \sim Ca^{1/3}$ $\theta_a \sim Ca^{1/2}$



PSLFI in The Vicinity of Contact Line

- Resolve the precursor layer film in front of a spreading drop by observing drop in fringe visibility, m, and variation of drop height, h.
- Spreading of viscous Newtonian silicone oil on silicon substrate.

drop in fringe visibility, m, at beginning of the precursor layer



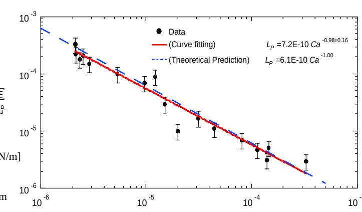
Precursor Layer Length, L_P

- L_P is determined by comparing spatial variation of visibility and drop heights.
- Theoretical prediction: $L_P \sim (SA/6\pi\sigma^2)^{1/2}/Ca$ (De Gennes, 1985).

$$\frac{L_P}{\sqrt{SA/6\pi\sigma^2}} \sim \frac{1}{Ca}$$

where:
A: Hamaker constant [J]
S: Spreading coefficient [N/m]

For our experiment:
$(SA/6\pi\sigma^2)^{1/2} = 6.1\times10^{-10}$ m



Conclusions

- Non-invasive optical technique has been used to investigate dynamical evolution at the vicinity of the dynamic contact line of spreading droplets.
- Existence of an "inflection point" close to the contact line is confirmed.
  - Macroscopic spreading is of form predicted by "Tanner's Law": $\theta_a \sim Ca^{1/3}$.
- Length of precursor layer, L_P, is determined by comparing spatial variation of visibility and drop heights.
  - L_P, is inversely proportional to the capillary number of the spreading drop as theory predicted.
- Shape of spreading drop on inclined plate close to the contact line follows the similarity solution given by Huppert (1982).
  - For $Bo \sim O(1)$, dynamic contact angle follows a new regime: $\theta_a \sim Ca^{1/2}$.
  - For $Bo \ll 1$, regardless of the slop of plate, $\theta_a \sim Ca^{1/3}$.

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