Super-wetting and Super-spreading

Glen McHale, M. I. Newton, N. J. Shirtcliffe, C. C. Perry and S. Aqil

School of Science
The Nottingham Trent University
Nottingham NG11 8NS, UK

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Overview

1. Roughness Induced Complete Wetting
    - Equilibrium wetting
    - Wenzel v Cassie form of films
2. Dynamic Wetting
    - Contact line forces
    - de Gennes-Hoffmann equation and Tanner's Law
3. Experimental Results
    - PDMS on lithographic surfaces
    - Sprout leaves

Superwetting – Wenzel v Cassie

Wenzel's Equation

- Based on roughness, *r*

$$\cos\theta_e^W = r\cos\theta_e^S$$

- Superwetting (i.e. $\theta_e^s \rightarrow \theta_e^w = 0^o$) when

$$\theta_e^S < \cos^{-1}(1/r)$$

- *Ignores any pre-wetting film*

Cassie-Baxter (Complete Wetting)

- Two surfaces: fractions φ_s and (1- φ_s)

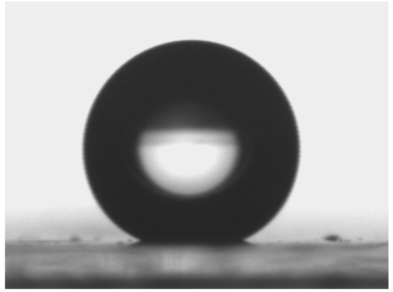
$$\cos\theta_e^c = \varphi_s\cos\theta_1 + (1-\varphi_s)\cos\theta_2$$

- Film $\rightarrow$ Solid θ_e^s & Own liquid $\theta = 0^o$

$$\cos\theta_e^c = 1 + \varphi_s\left(\cos\theta_e^s - 1\right)$$

- *Assumes film exists and drop volume loss to film is small*

Drops on SU-8 Photoresist Pillars



- SU-8 Photoresist

  Flat and bare 84°, flat and hydrophobised 115°,

  tall and 5 μm pattern 155°

- Super-wetting

  SU-8 photoresist

  D =15 μm, *L* = 2*D*

  h = 43 μm

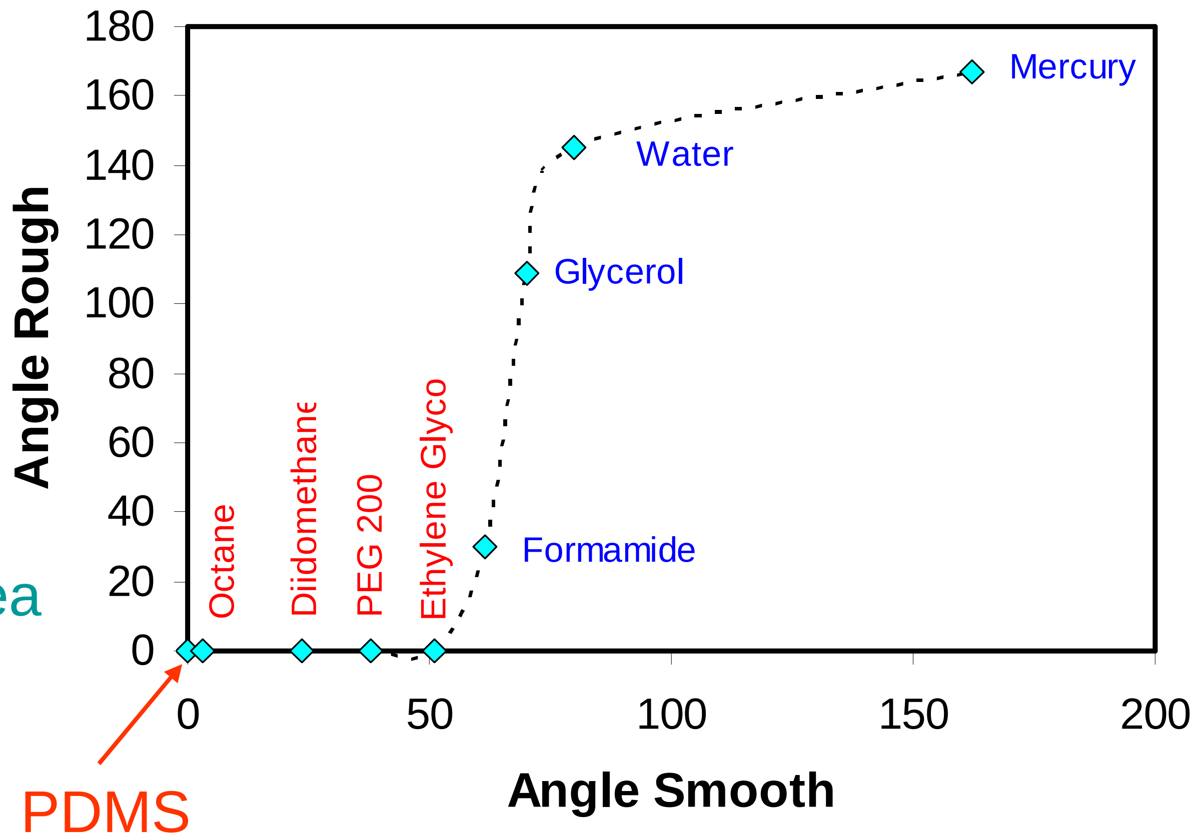
- Wenzel Type

  1 μl drop on texture

  over 1 cm × 1 cm area

  Drop volume can be

  completely imbibed



Theory of Spreading

- Driving Force and Viscous Dissipation

  Usual force is unresolved component of surface tension

  $$F = \gamma_{LV}\left(\cos\theta_e^s - \cos\theta\right)$$

  Viscous dissipation is

  $$T\dot{S} \approx \eta v_E^2 \big/ \theta$$

- Hoffmann-de Gennes

  Dissipation must equal $v_E F$

  $$v_E \propto \theta\left(\cos\theta_e^s - \cos\theta\right) \propto \theta\left(\theta^2 - \theta_e^{s\,2}\right)$$

  Edge speed ∝ cube of dynamic angle (θ_e^s=0º)

- Tanner's Law

  Small drop of non-volatile liquid (vol const), complete wetting (θ_e^s=0º) and solve

  $$\theta = \frac{A}{\left(t + t_o\right)^{3/10}}$$

Spreading on Rough Surfaces

- Driving Force Modified

  Roughness modifies the component of surface tension

$$F = \gamma_{LV}\left(r\cos\theta_e^s - \cos\theta\right)$$

- Hoffmann-de Gennes

  Roughness term

$$v_E \propto (r-1)\theta + \theta\left(\theta^2 - r\theta_e^{s2}\right)\Big/2$$

  Edge speed ∝ dynamic angle (r>1* and *θ_e^s=0º)

- Tanner's Law

  Small drop of non-volatile liquid (vol const), complete wetting (θ_e^s=0º), *r*>>1 and solve

$$\theta = \frac{A}{(t+t_o)^{3/4}}$$

Summary of Exponents

- Spherical Cap Droplet/Volume Conserved

Characteristic length and speed $\kappa^{-1} = \sqrt{\dfrac{\gamma_{LV}}{\rho g}}$ $v^* = \dfrac{\gamma_{LV}}{\eta}$

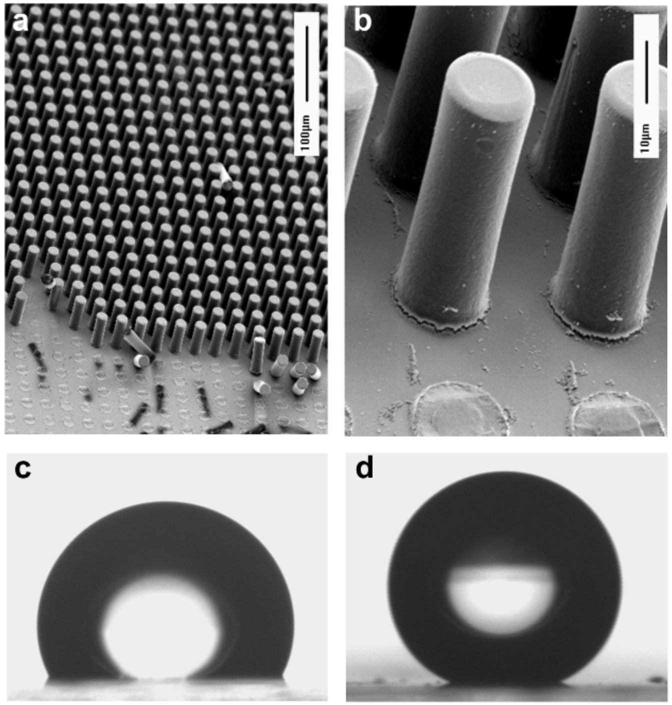
Modified de-Gennes $\theta \propto \left(\dfrac{V^{1/3}}{v^*}\right)^n \dfrac{1}{(t+t_o)^n}$

Modified Tanner $v_E \propto v^* \theta^p$

	Exponent	Exponent	Flat	Rough
v_E	$(1-n)/n$	p	3	1
θ	$-n$	$-3/(3p+1)$	-3/10	-3/4
d	$n/3$	$1/(3p+1)$	1/10	1/4
R	$4n/3$	$4/(3p+1)$	4/10	1
h_o	$-2n/3$	$-2/(3p+1)$	-1/5	-1/2
A_{SL}	$2n/3$	$2/(3p+1)$	2/10	1/2

Cubic → Linear

Drops on SU-8 Photoresist Pillars



- SU-8 Photoresist and Water

  a) and b)Pillars D=15 μm, L = 2D

  c) Flat and hydrophobic, d) tall and hydrophobic

- Super-Spreading Experiments

  Drops of PDMS, volume ~ μl, Size < κ^{-1}

  Measure dynamic angle, radii, contact diameter, volume, etc, as pillar height increased

- Analysis of Dynamics

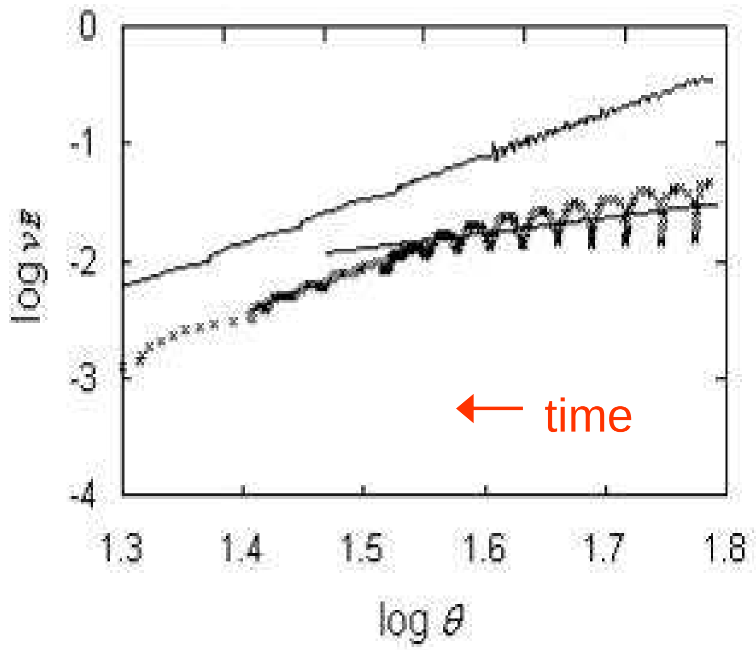
  Tanner's Law: Fitting to θ v t & d v t i.e. to find n

  Hoffmann-de Genne: Fitting to v_E v θ i.e. to find p

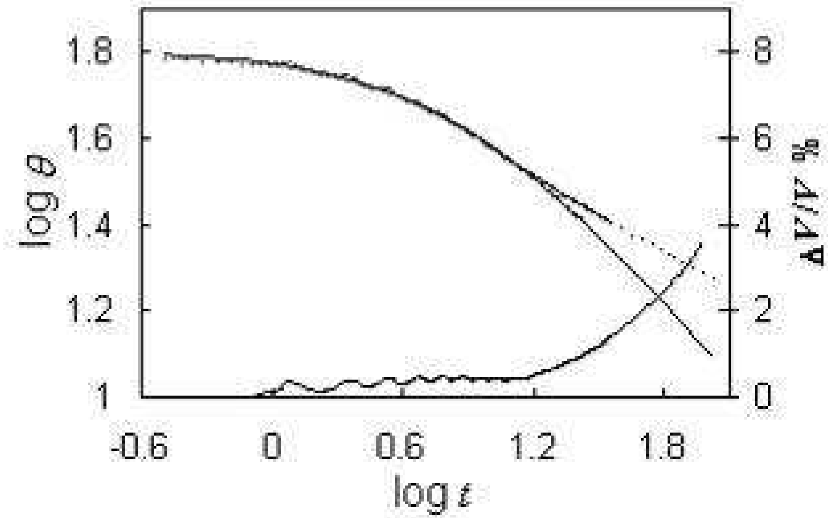
  Potential Problem: Constant volume and axial symmetry needed

Example Result on Tall Pillars

- Flat and Tall
  - Pillars D=15 μm, L = 2D, h = 45 μm
  - PDMS Spreading to 0º
  - Upper data is flat surface (slope = 3)
    - Upper data has been shifted up by 0.5
  - Lower data is textured (slope = 1.3)



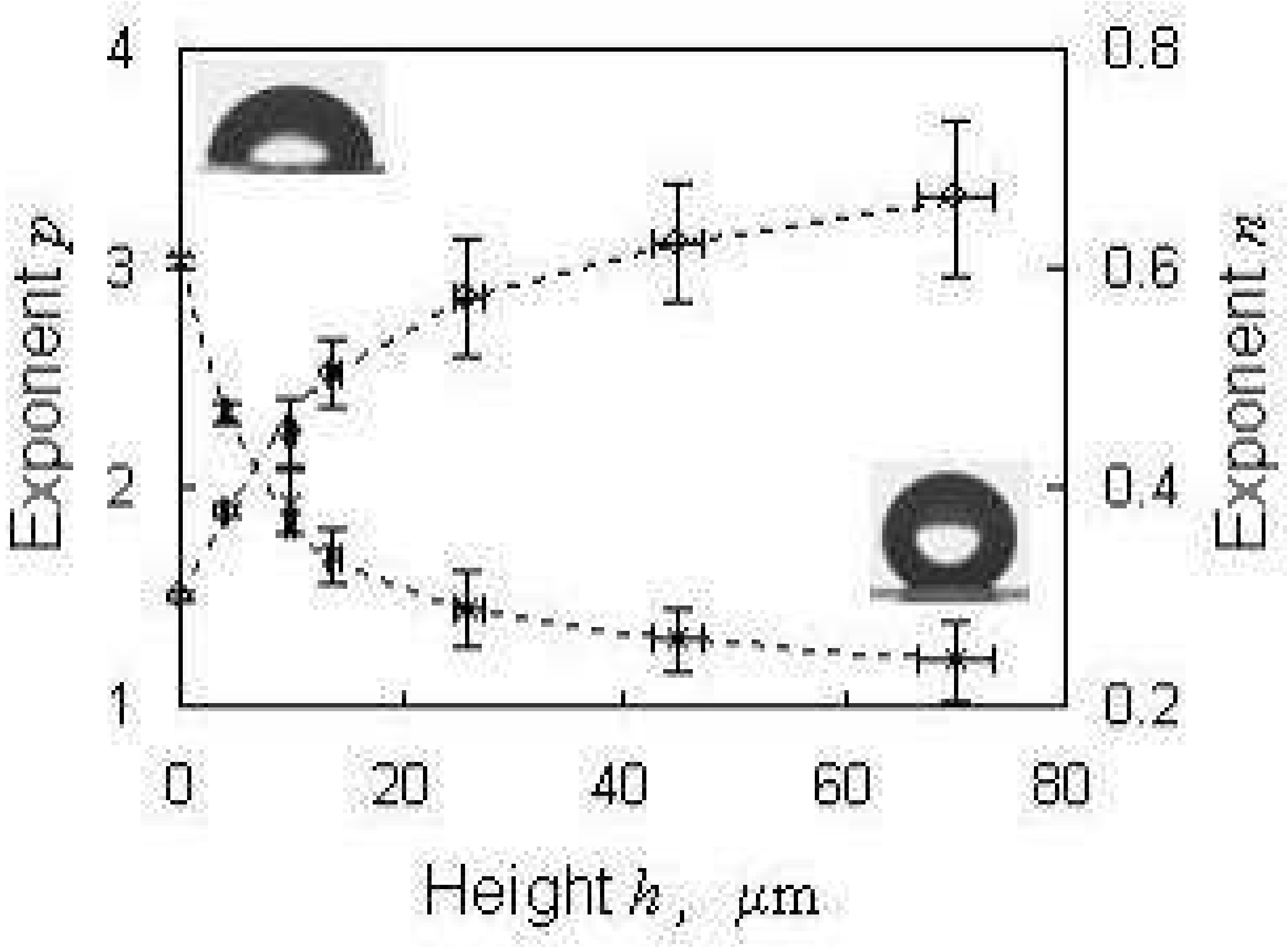
- Primary Features
  - Periodic osc's (period is 30 μm)
    - "stick-slip" on lattice of pillars
  - Volume constant over initial period
    - at later times pattern fills ahead of drop
    - raises questions of pre-wetting, slip, etc



Experimental Data Set on Pillars

- Data for Exponents *p* and *n*

  Cubic to linear transition is observed as pillar height increases

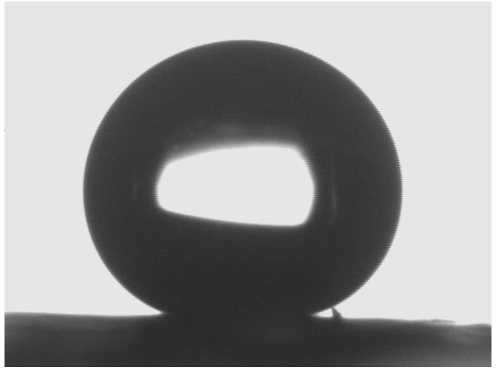


Experimental Data on Leaves

- Sprout Leaf

  brassica oleracea

  Super-hydrophobic θ>165°



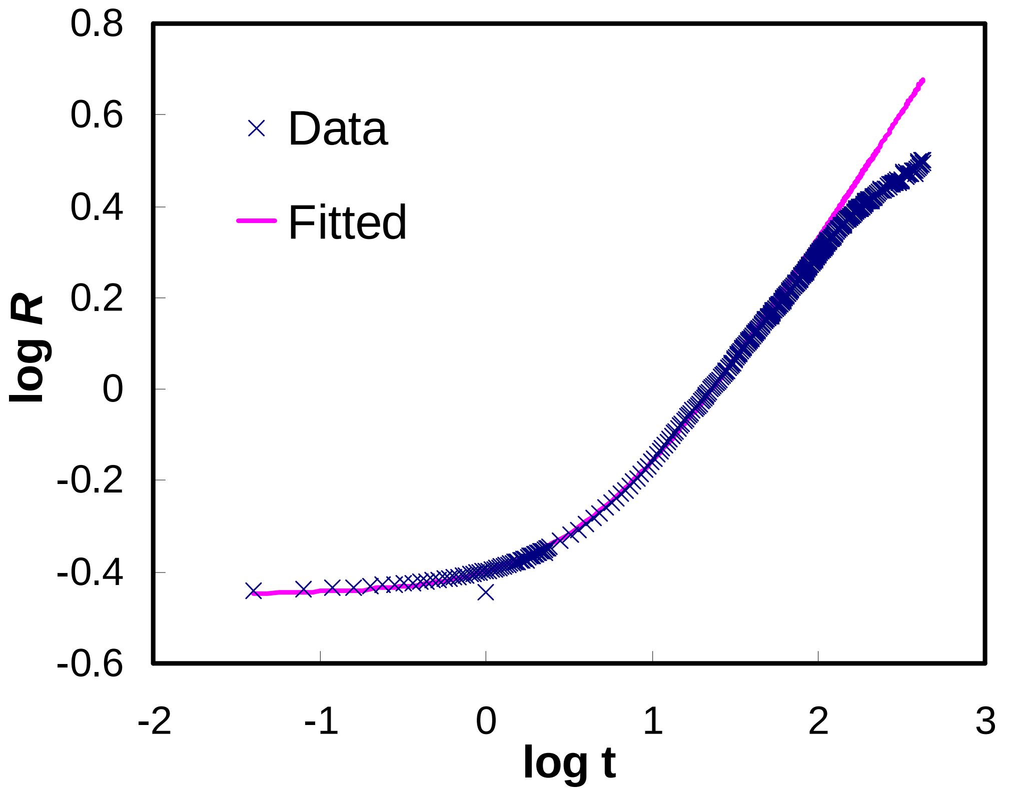
- Fitting

  θ, d and v_E unreliable

  baseline problem

  use spherical radius, R v t

  E.g. $R \sim (t+t_o)^{0.565} \rightarrow p \sim 2$



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