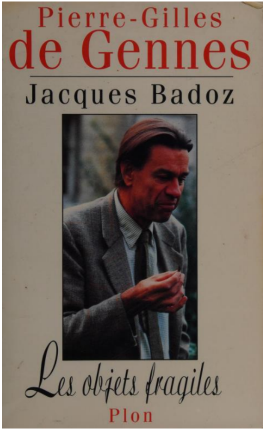
La température des objets savonneux

François Boulogne

avec Frédéric Restagno & Emmanuelle Rio

Soap Films and Foams, Fragile Objects

Dans une bulle de savon il y a aussi toutes les étapes de la vie. Elle naît, croît et se développe, vieillit et finalement... disparaît.



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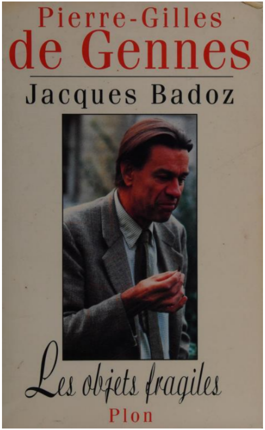
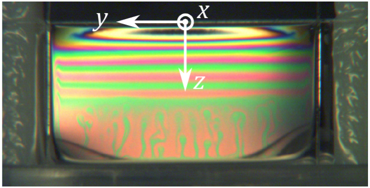


Causes of soap film rupture?

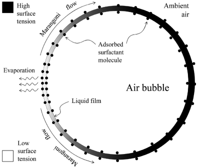
- Gravity and capillary drainage
- Marginal regeneration
- Evaporation

Evaporation contributes to soap film rupture

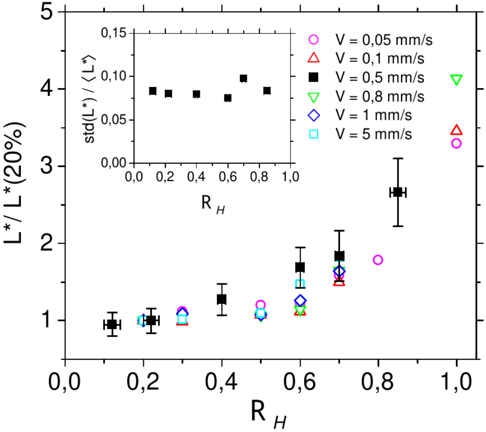


Rupture length $L^{\star}$

Champougny *et al.*, Langmuir, 2018



Li & Stevenson, Langmuir, 2012



Evaporation induces a film thinning

See also: Bourouiba *et al.*, Villermaux *et al.*, Lorenceau *et al.*, Rouyer *et al.*, Quéré *et al.*, Stevenson *et al.* . . .

Psychrometry

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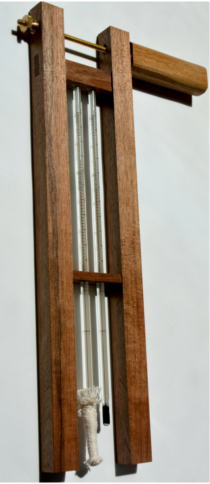

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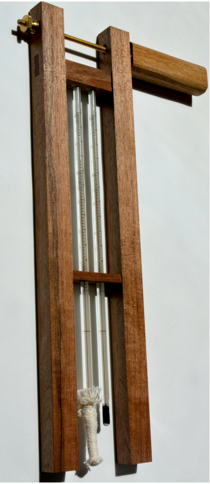

$$\Delta e^\star = \mathcal{A}\, P\, \Delta T^\star$$

- $\Delta e^\star = e_\infty - e_\mathrm{i}$
  vapor pressure difference dry & wet bulbs
- P is the atmospheric pressure
- $\mathcal{A}$ the psychrometer coefficient
  ... 150 years of research hidden in it!

From $\Delta e^\star$ we can derive $\mathcal{R}_\mathrm{H}$

Temperature of Soap Films

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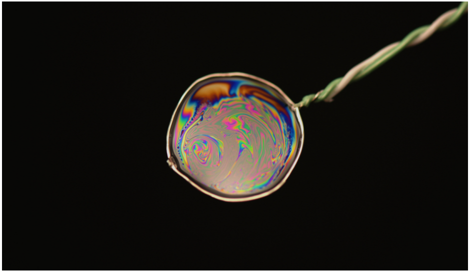
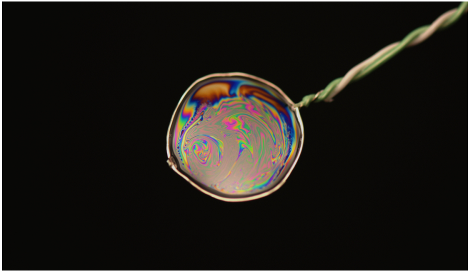


Soap film on a thermocouple probe
Diameter $2R = 12$ mm

- Solution of Fairy (Dishwashing soap)
- Glycerol concentration Γ_{g}

Temperature of a Soap Film



Soap film on a thermocouple probe
Diameter $2R = 12$ mm

- Solution of Fairy (Dishwashing soap)
- Glycerol concentration Γ_{g}: ability to tune the evaporation rate

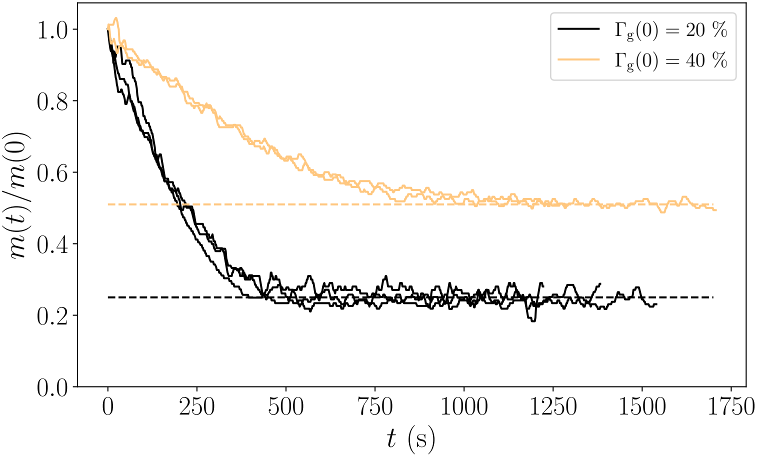
$$e_{\mathrm{sat}}(\Gamma_{\mathrm{g}}, T) = e^0_{\mathrm{sat}}(T)\frac{1-\Gamma_{\mathrm{g}}}{1+\Gamma_{\mathrm{g}}(a-1)}$$

$a \approx 0.2$

With Antoine equation

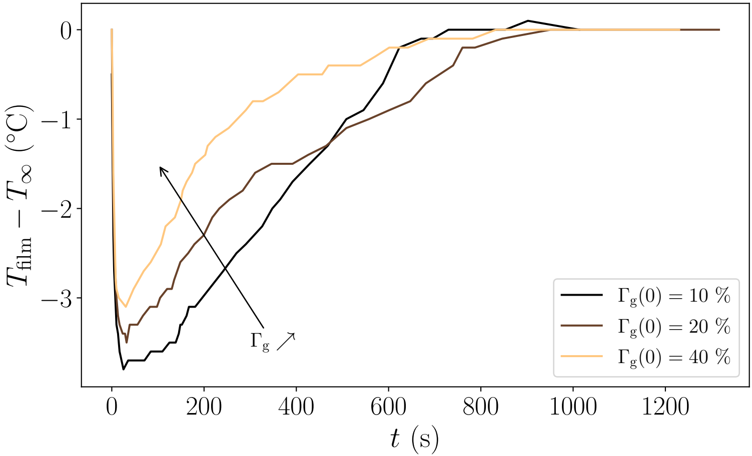
$$e^0_{\mathrm{sat}}(T) = e^\circ\, 10^{A-\frac{B}{C+T}}$$

Weight dynamics

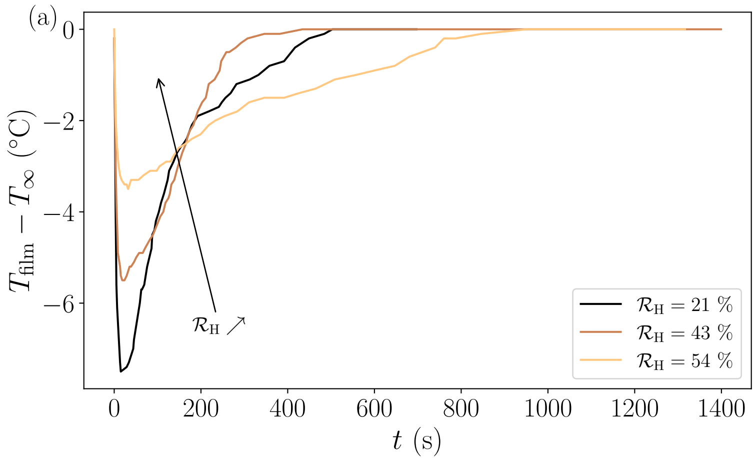


$$\Gamma_{\rm g}^{\rm eq} = \frac{1 - \mathcal{R}_{\rm H}}{1 + (a-1)\mathcal{R}_{\rm H}}$$

Temperature: Effect of glycerol



Temperature: Effect of relative humidity



How to predict the minimum temperature?

Psychrometer Coefficient

h_{ev} enthalpy of vaporization

Heat flux balance

$$h_{\mathrm{ev}}\Phi_{\mathrm{ev}} + Q_h + Q_{\mathrm{rad}} = 0$$

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Heat flux balance

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Evaporative flux ($\triangle c = 0$)

$$\Phi_{\text{ev}} = 4\mathcal{D}R\Delta c^{\star}$$

$$\Delta c^{\star} = c_{\infty} - c_{\text{sat}}(\Gamma, T_{\text{i}})$$

Cooke, 1967; Lebedev 1965

Psychrometer Coefficient

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$$\Delta T^{\star} = T_{\infty} - T_{\mathrm{i}}$$

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Heat flux from the atmosphere

$$Q_{\mathrm{h}} = 4 \lambda_{\mathrm{air}} R \Delta T^{\star}$$

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Radiation (Stefan-Boltzmann)

$$Q_{\text{rad}} = \pi R^2 \epsilon\sigma (T_\infty^4 - {T_{\text{i}}}^4)$$

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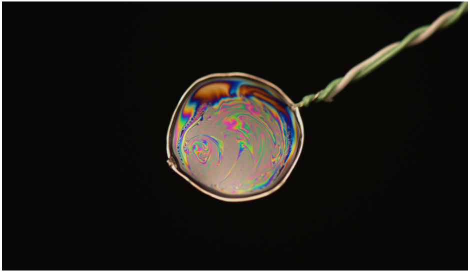
Psychrometric equation

$$\Delta e^\star = \mathcal{A}\, P\, \Delta T^\star$$

Minimum Temperature

$$\Delta e^\star = -P \frac{M_{\rm air}}{\rho_{\rm air} M_{\rm w}} \frac{\lambda_{\rm air}}{\mathcal{D} h_{\rm ev}} \left(1 + \frac{\pi R \epsilon \sigma T_\infty^3}{\lambda_{\rm air}}\right) \Delta T^\star$$

Characteristic radius for $Q_{\rm rad} = Q_{\rm h}$: 7 mm.



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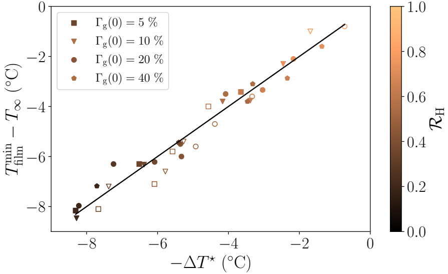

No adjustable parameter.

Boulogne, Restagno, Rio, PRL, 2022

Perspectives

Evaporation is not only a thinning effect
but also a cooling effect
not quantified in the litterature on soap films

Order of magnitude: 2 to 8°C

Consequence on stability?

Thank you for your attention