4. Dusty Blot

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Problem

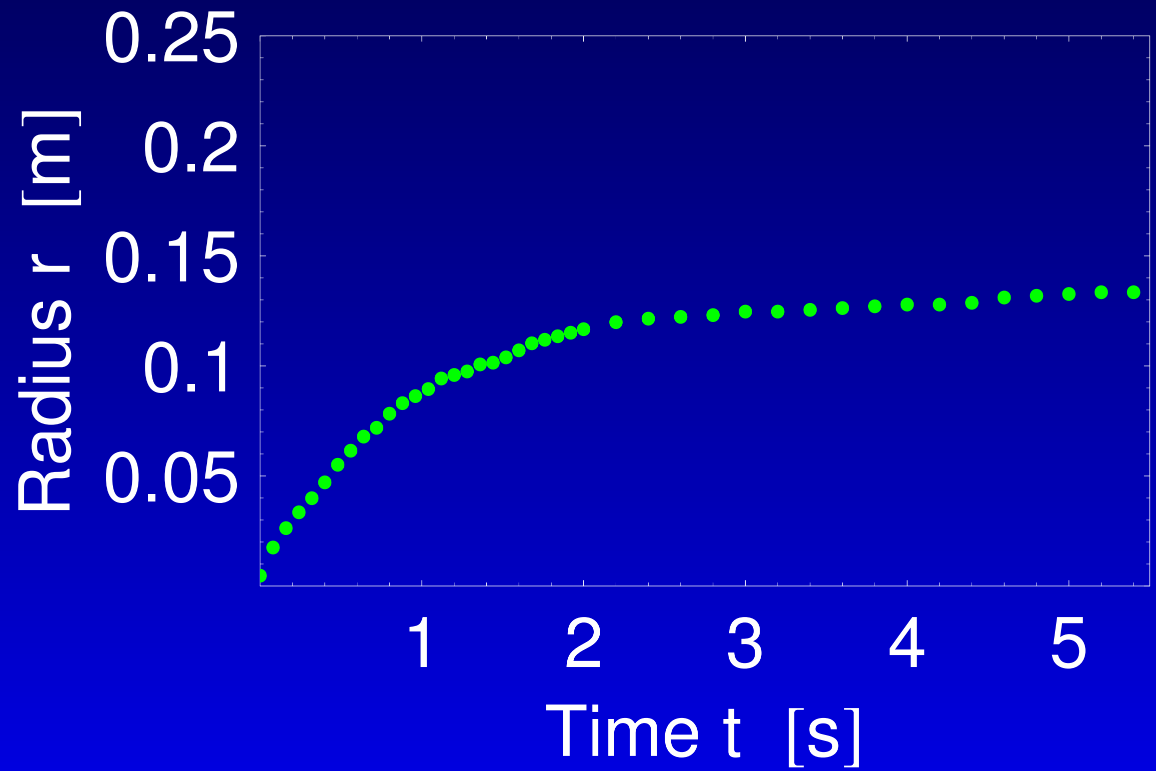
Describe and explain the dynamics of the patterns you observe when some dry dust (e.g. coffee powder or flour) is poured onto a water surface. Study the dependence of the observed phenomena on the relevant parameters.

Overview

- Basic Experiments
  - Experimental Values for Blot-spreading
  - Reasons for Spreading
  - Measurement of Surface Pressure
- Theory
  - Forces on Blot
  - Equation of Blot-spreading
- Experiment vs. Theory

Spreading of Blot

Blot-radius r in dependence of spreading time t for flour:



Basic Observations

- Other dried organic dusts spread too
- Sand, aluminum and other non-organic powders do not spread
- Cup spills over meniscus where blot reaches edge
- Slower spreading in detergent-solution
- Detergents also spread

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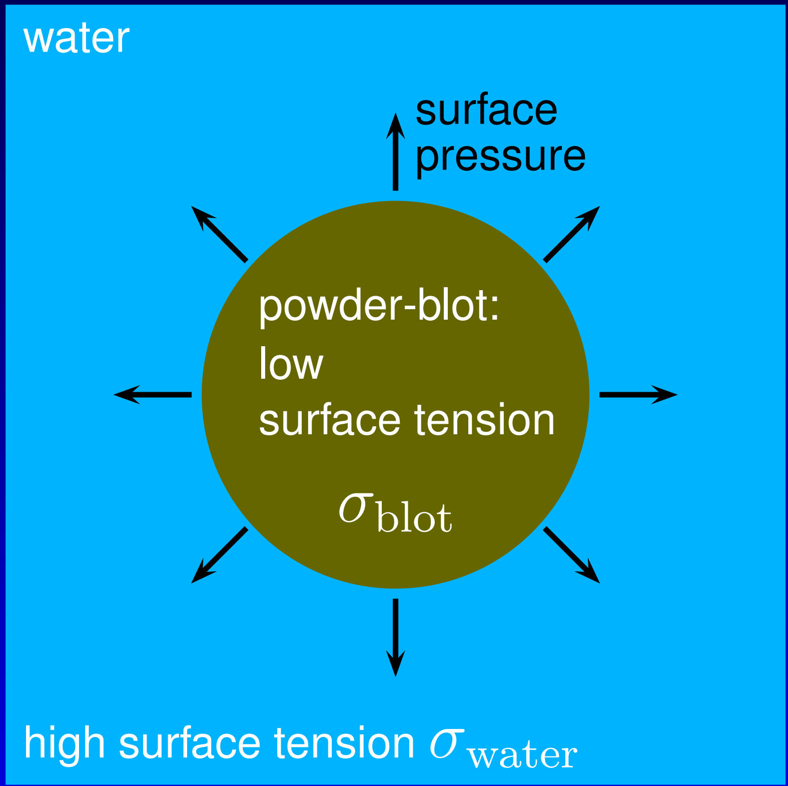
Detergents reduce surface tension!

- Powders too? – Reason for spreading?

Surface Pressure

Reduction of surface tension can explain spreading:

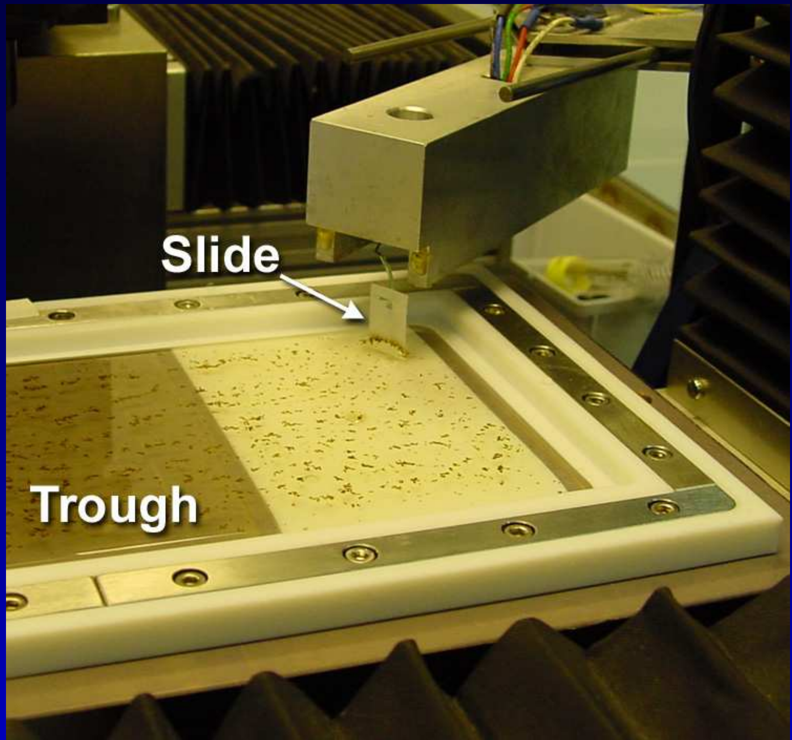


- surface pressure: $\pi = \sigma_{\text{water}} - \sigma_{\text{blot}}$
- acts radially
- inflates blot
- until concentration of surfactants becomes negligible:

$$\begin{aligned} \sigma_{\text{water}} &\approx \sigma_{\text{blot}} \\ \Rightarrow \quad \pi &\approx 0 \end{aligned}$$

Measuring Surface Pressure

Method: Wilhelmi Balance



- slide touches liquid
- tension σ pulls slide into liquid
- force F is measured
- a change of σ changes F
- pure water: $F \equiv 0$

Surface pressure $\pi = \sigma_{\text{water}} - \sigma_{\text{blot}}$

Measurement Results

- detergent (soap):

$$\pi \approx 20 \ldots 30 \cdot 10^{-3}\,\mathrm{N\,m^{-1}}$$

- coffee:

$$\pi \approx 15 \ldots 33 \cdot 10^{-3}\,\mathrm{N\,m^{-1}}$$

- flour:

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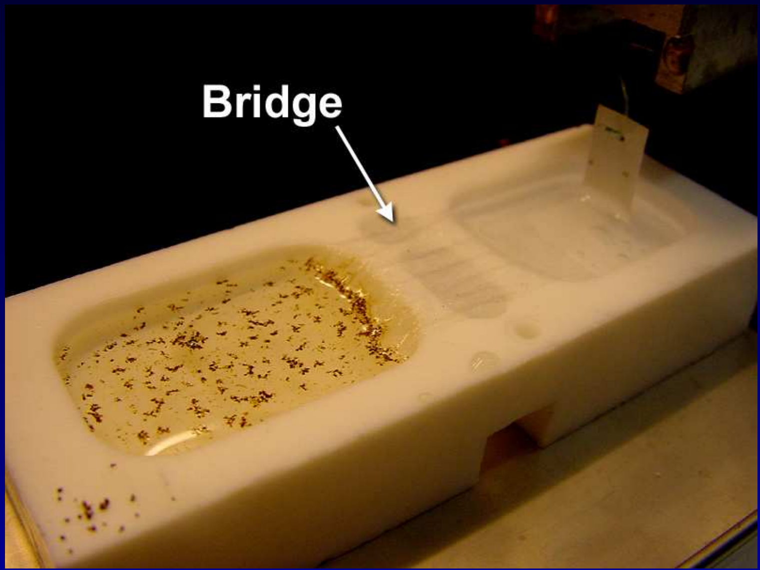
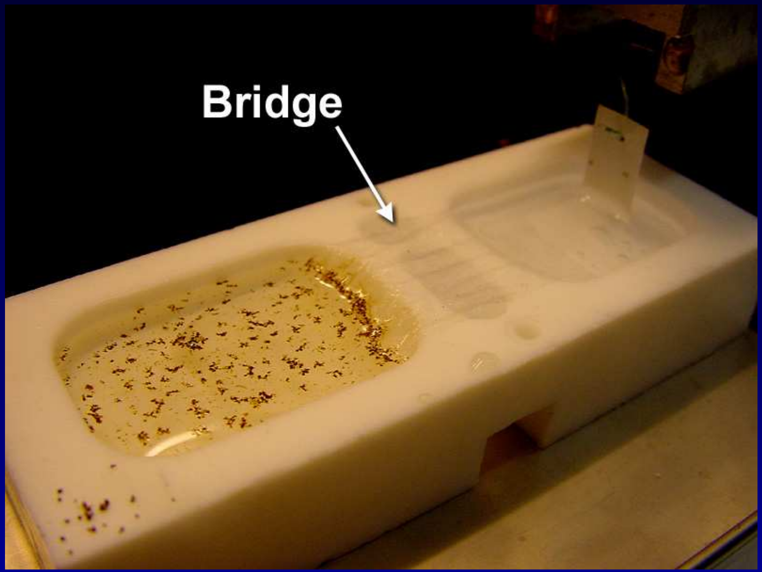
But particles are not essential for reduction of surface tension!

Measurement without Particles



- two volumes of water
- bridged by tissue
- pour powder left
- measure π right

Measurement without Particles



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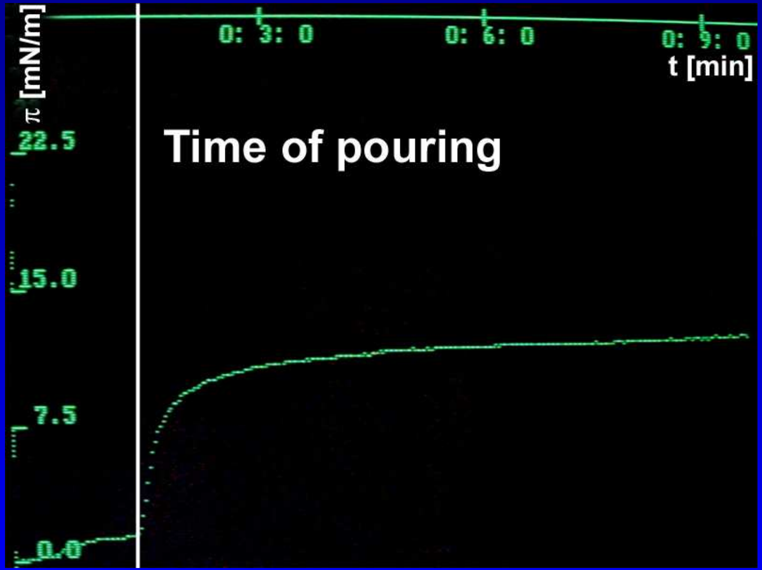


- at time of pouring π jumps up

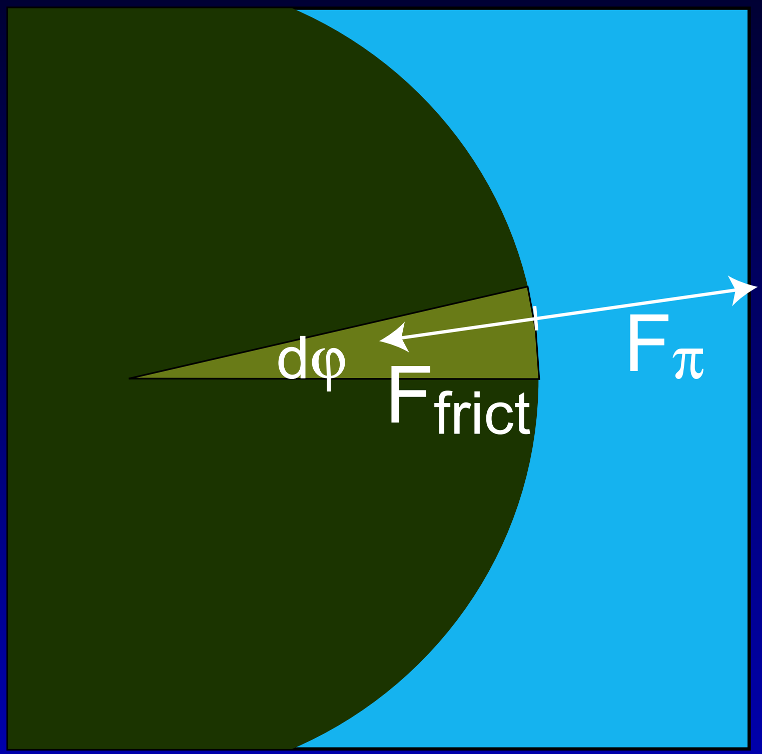
Conclusion from Experiments

- Water extracts surface active molecules (fatty acids, lipids) from organic powders

Conclusion from Experiments

- Surfactant-film spreads rapidly and accelerates water on surface
- Powder swims on the surface layer

Forces on Blot



- Accelerating Pressure force

$$F_\pi$$

- Frictional force

$$F_{\text{frict}}$$

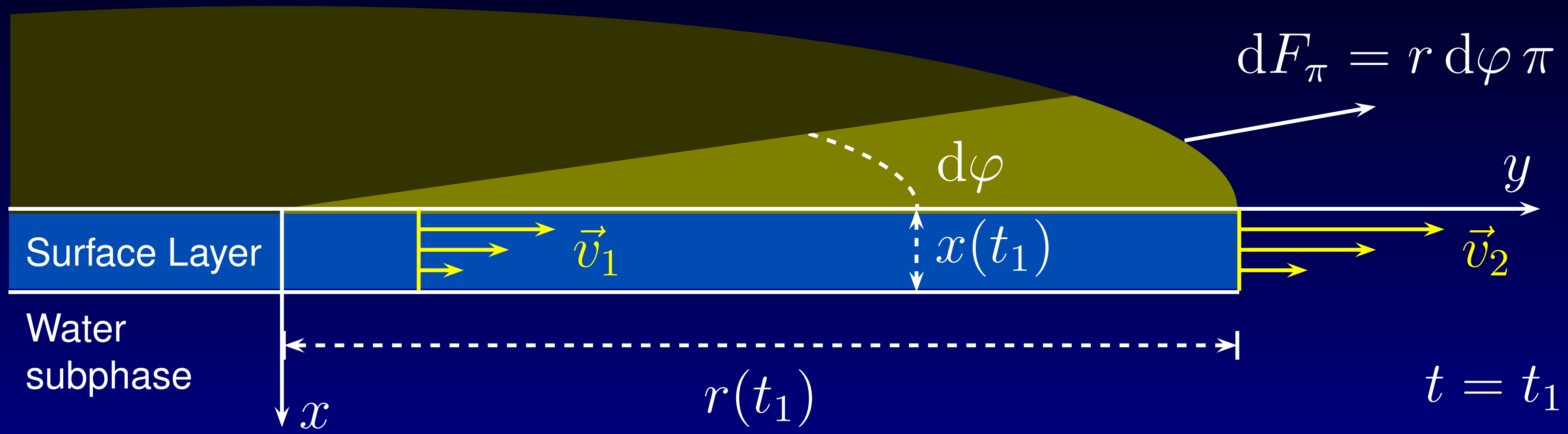
Surface Pressure in Theory

- Formula can be derived from entropy
- Surface pressure depends on:
  - concentration c
  - surfactant specific constants a_0 and a_1
  - temperature T of subphase

$$\pi(c) = R\,T a_0 \ln(1 + a_1 c)$$

$$\Longrightarrow \mathrm{d}F_\pi = r\,\mathrm{d}\varphi\,\pi(r)$$

Friction in Theory



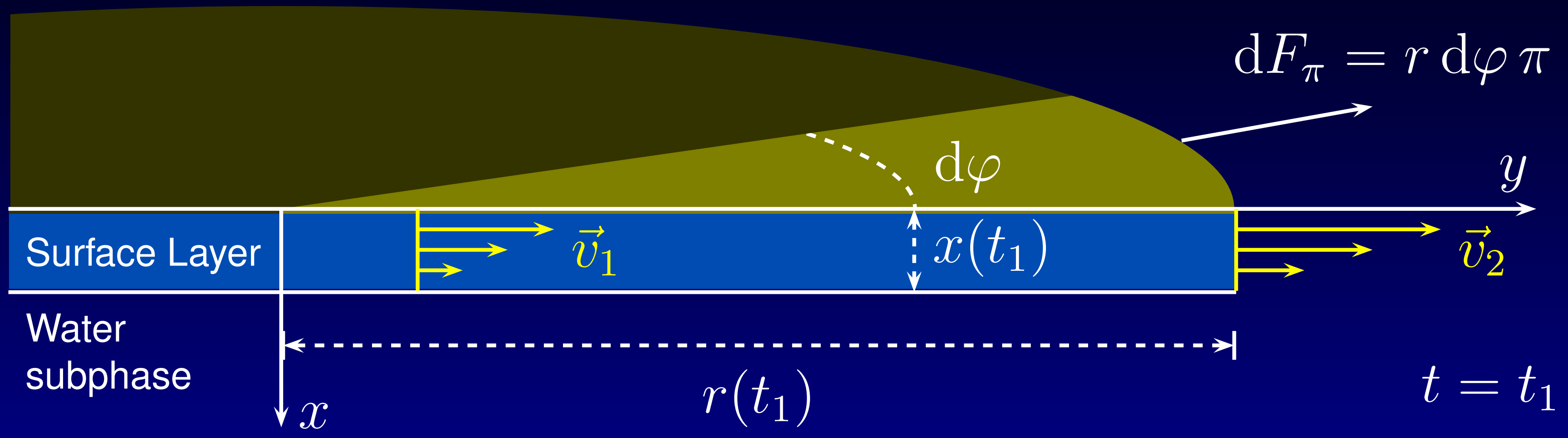
- Surface layer accelerates the subphase

$$\mathrm{d}F_{\mathrm{frict}} = a\,r^2\dot{r}\,\mathrm{d}\varphi\,\frac{\eta}{x(t)}$$

- With height of layer $x(t) \sim \sqrt{\frac{\eta}{\rho}t}$:

$$\mathrm{d}F_{\mathrm{frict}} = a_2\,r^2\dot{r}\,\mathrm{d}\varphi\,\sqrt{\frac{\rho\eta}{t}}$$

Equation of Motion

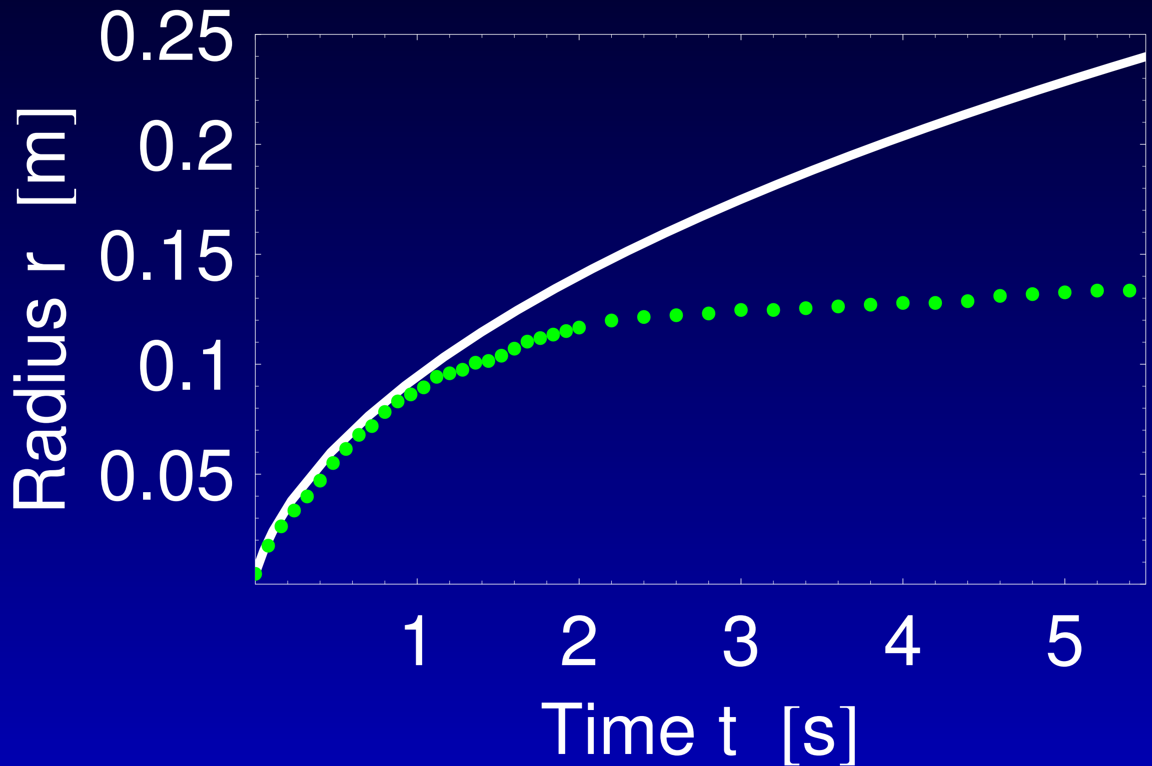


$$\mathrm{d}F_{\mathrm{frict}} = \mathrm{d}F_\pi$$

$$a_2\, r^2 \dot{r}\, \mathrm{d}\varphi \sqrt{\frac{\rho\eta}{t}} = r\,\mathrm{d}\varphi\,\pi(r)$$

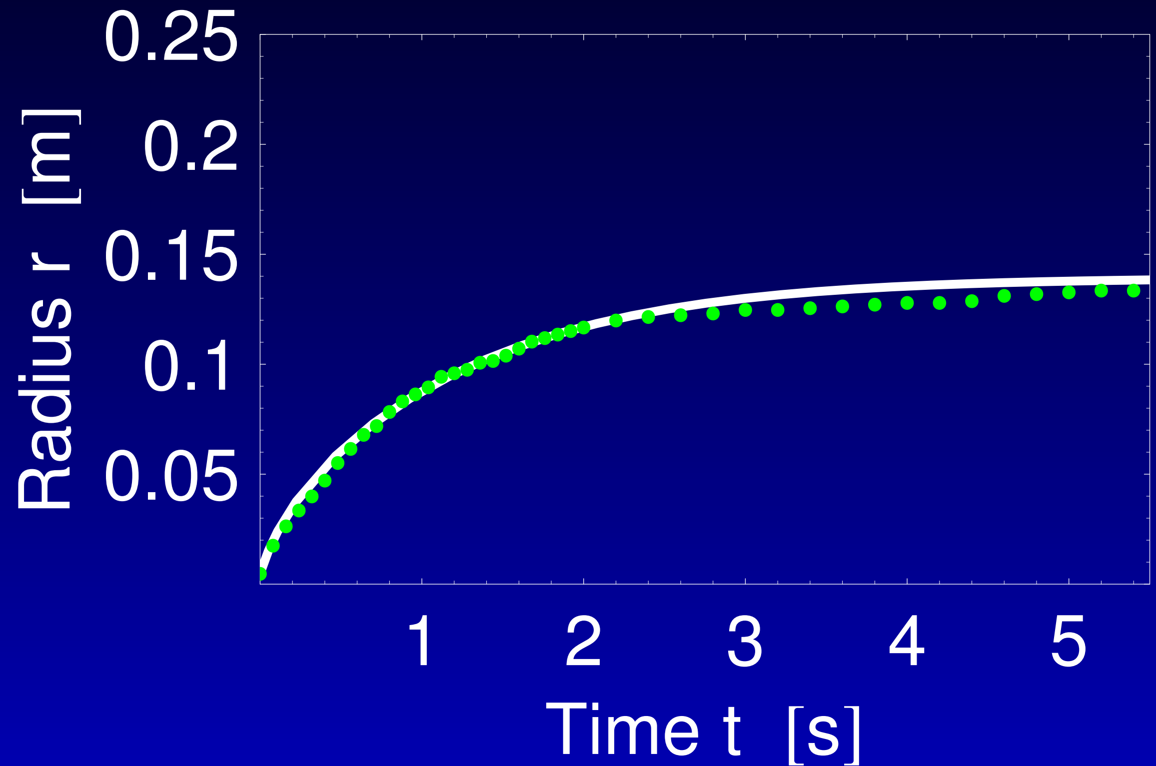
$$a_2\, r \dot{r} \sqrt{\frac{\rho\eta}{t}} = R\,T a_0 \ln(1 + a_1 \frac{m}{\pi r^2})$$

Theory vs. Experiment



- Curve fits well at beginning of process
  $\Longrightarrow$ Does diffusion play a role at the end?

Theory vs. Experiment



- Added diffusion term:

$$a_2\, r\dot{r}\sqrt{\frac{\rho\eta}{t}} = RT a_0 \ln\left(1 + \frac{a_1 m}{\pi\, r^2}\, \mathrm{e}^{-a_3 t}\right); \quad a_3 \sim 1$$

Summary

- Water can solve surface active substances from powders
- Surfactants reduce surface tension
- Surface pressure is the reason for spreading
- The higher the surface pressure the faster the spreading
- Spreading speed varies strongly from powder to powder

Practical Application

- Finally a practical application of the phenomenon...

Movie

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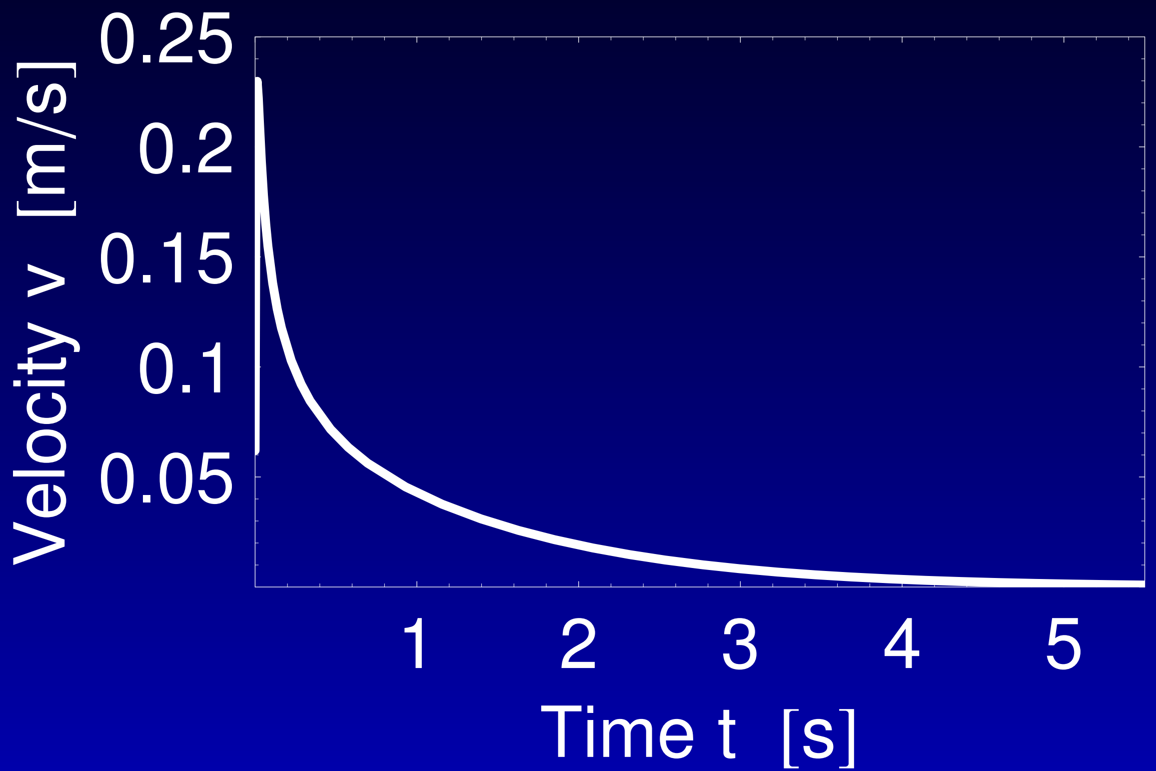
Appendix - Velocity for Flour



- Velocity of spreading for flour