The spreading of emulsions on thick fluid layers

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**Aim of the study**
Surfactants used in chemical encapsulation and delivery to interfaces. Impact of surfactant solubility on spreading of droplet-encapsulated material.

**Conclusions**
- Finite spreading
- Rich dynamics showing 2D turbulence
- Spreading properties set by surfactant affinity with water

**Materials**

<table>
<thead>
<tr>
<th>Surfactant family</th>
<th>Alkyl chain</th>
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<tbody>
<tr>
<td>Sodium alkyl sulfates</td>
<td>C₈C₁₂</td>
</tr>
<tr>
<td>C₆TAB</td>
<td>C₁₀C₁₄</td>
</tr>
<tr>
<td>C₇TAC</td>
<td>C₁₂C₁₆</td>
</tr>
</tbody>
</table>

2:1 oil-in-water emulsions:
- [surf] = 260 mM
- dₜₐₚ = 10 μm

230 × Mₓ < 320 g.mol⁻¹
38 < γₘₐₚ < 42 mN.m⁻¹ above the cmc

**Set-up**

Qₒ = 0.2 mL.min⁻¹

|h > 2 mm |
| L = 260 mm |

Ultra-pure water

Constant supply of emulsion to the surface of a layer of ultra-pure water at a flow rate low enough to ensure stability.

**1. Finite spreading distance, 2D turbulence**

(a) Top view

(b) High ρₒ

Inside the disk of radius rₒ, low density of fast-moving oil droplets ρₒ-

Outside the disk, high density of slow-moving droplets.

Growth of pairs of vortices (similar to Rayleigh-Taylor mushrooms) resulting from the impact of the fast droplets in the dense region.

Low ρₒ

**2. Interpretation**

Marangoni stress = motion of surfactant molecules AND oil droplets

Solubilization of the surfactants during spreading = Fast motion of the oil droplets at a velocity u(h) in the corona between the source (radius rₒ) and the disk boundary (radius rₛ). Finiteness of spreading.

**3. A first model**

Fluid dynamics of the layer

Stokes equation

\[ u(h) = \frac{h}{\eta \frac{d\gamma}{d\Gamma}} \frac{d\gamma}{dx} \]

Evolution of the surfactant surface concentration

Diffusion-convection equation

\[ \frac{d}{dx} \left( u(h) \Gamma \right) = -kₐ \Gamma + Dₗ \frac{d \Gamma}{dx} \]

Surfactant parameters:
- Surface concentration \( \Gamma \)
- Desorption coefficient \( kₐ \)

Layer parameters: interfacial tension \( \gamma \)

**4. Test of the model**

(a) Corona radius rₒ-rₛ varies over 2 orders of magnitude as the surfactant is changed.

For all surfactants, the corona radius reaches a plateau \( rₜₜₚ-rₒ \) and then starts to decrease.

(b) First, we identify \( \xi \) with \( rₜₜₚ-rₛ \), which we plot against \( kₐ \). We see that \( rₜₜₚ-rₜₜₚ \) does not follow the \( kₐ^{−1/2} \) scaling predicted by our first model.

(c) A plot against the critical micellar concentration (cmc) of the surfactants indicates that the affinity of the surfactant with water sets the spreading properties.

**5. Perspectives**

- Modification of the convection equation to account for the importance of the affinity: bulk diffusion term?
- Study of the instability of the ring surrounding the corona
- Study of the 2D turbulence
- Can we understand the fast flow towards the center of the corona (indicated by the white arrow on the images below) when the source is removed?

Scale bar: 10 mm