Role of surfactant mobility on bubble dynamics in tubes

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Abstract

The rheology of foams and bubbles in confined geometries differs from plain liquid flows, as the interface-to-volume ratio is drastically increased [1]. In particular, the rheological properties of foams were shown to significantly vary with the interfacial mobility of the surfactant used to stabilize them [2]. Various viscous friction forces at the contact with the confining medium showing nonlinear dependencies influence its dynamics [3]. To study the forces at stake, bubble velocities in cylindrical, confined tubes were measured for different capillary radii, bubble lengths and inclination angles for two different surfactants. It could be shown, that the two chosen surfactants lead to different rheology, even though the predicted model were not met completely. In order to further develop a metrology tool, a wider range of surfactants needs to be explored to quickly provide information on surfactant's surface mobility by simply measuring velocities of confined bubbles in these surfactant solutions.

Surfactant arrangement
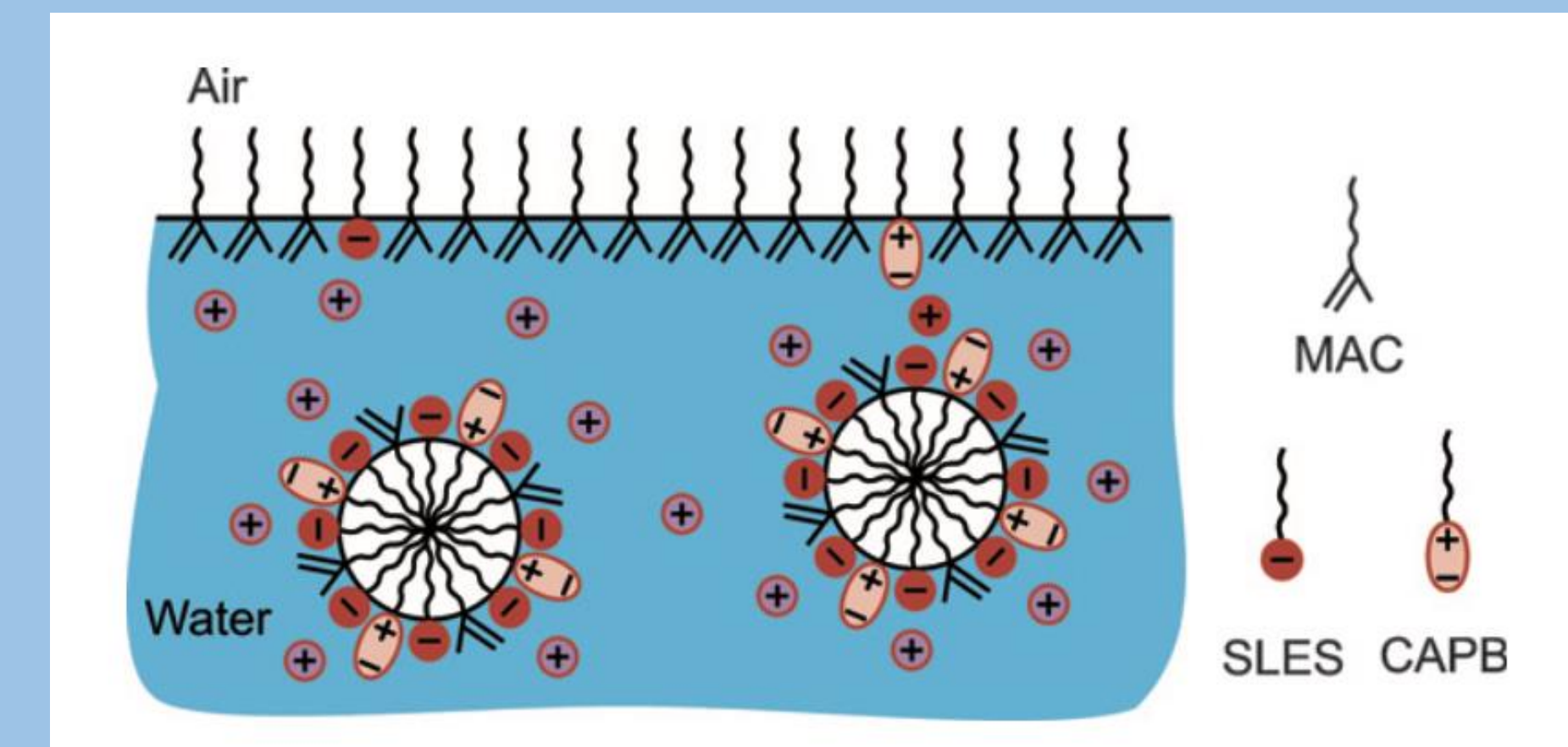
- Surfactant molecules gather at the interface forming a surfactant layer [2]

Measuring bubbles in confined tubes
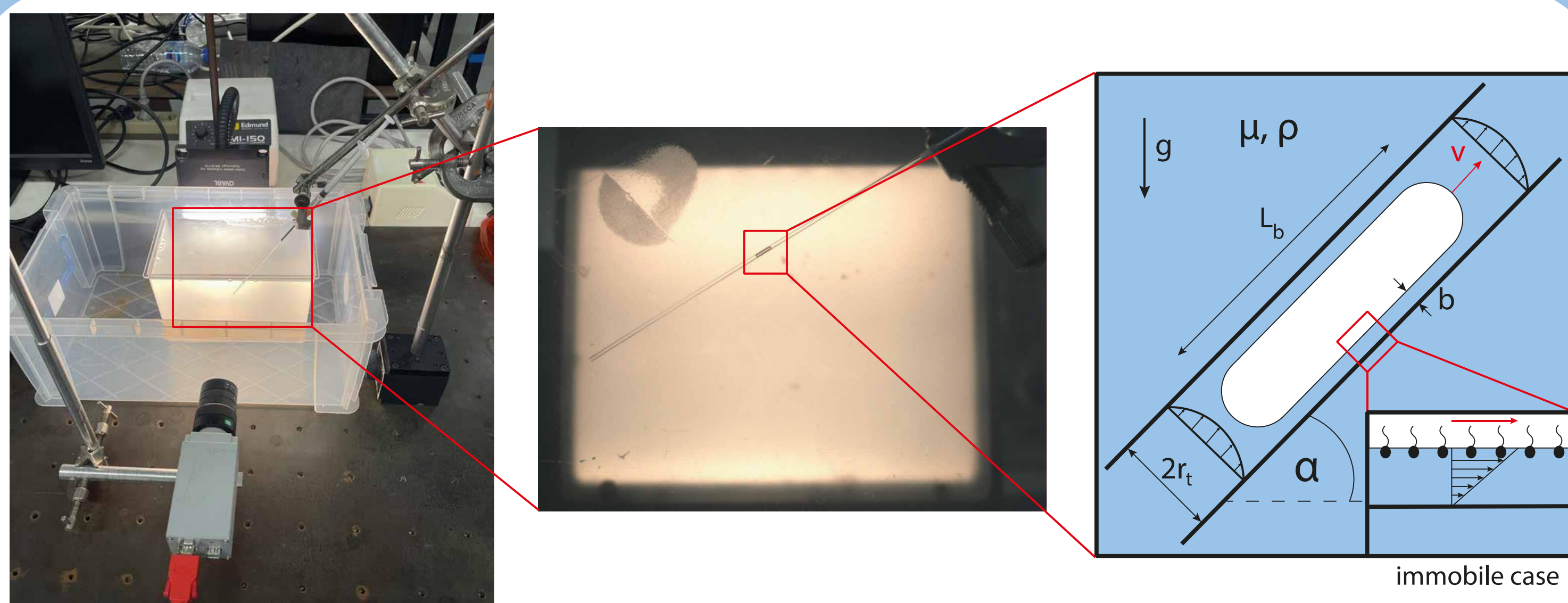
- Bubble inserted with a syringe inside a tube of length L_t
- Bubble length L_b, tube radius r_t and inclination angle α were varied systematically
- Surface tension γ, liquid density ρ and viscosity μ are fixed for given solution

Mobile and immobile surfactants:
- Mobile surfactant: 5.6 g/L of SDS mixed with water
- Low surface modulus, high surface mobility
- Immobile surfactant: mix of 6.6% SLES, 3.4% CAPB and 90% water, heat to 60°C and add 0.6% Mac
- High surface modulus, low surface mobility

Friction force through velocity

Buoyancy (driving force):
$$F_g \simeq \rho \pi r_t^2 L_b g \sin(\alpha)$$

Opposing forces:

- Dissipation in the bulk:
$$F_{\eta_1} \simeq 8\pi\mu V \left(L_t - L_b\right)$$

- Dissipation in the menisci:
$$F_{\eta_2} \simeq \alpha\gamma r_t \left(\mu V/\gamma\right)^{2/3}$$

- Dissipation in lubricating layer:
$$F_{\eta_3} \simeq \frac{2\pi}{1.34}\gamma L_b \left(\mu V/\gamma\right)^{1/3}$$

- Dissipation in the menisci is negligible
- Two limits for the expression of the capillary number depending on the opposing forces:

$$Ca_1 = \frac{\mu V_1}{\gamma} = \frac{\rho g r_t^2 \sin\alpha}{8\gamma}\left(\frac{L_b}{L_t - L_b}\right)$$

$$Ca_3 = \frac{\mu V_3}{\gamma} = \left(\frac{1.34}{2}\right)^3 \frac{(\rho g \sin\alpha)^3 r_t^6}{\gamma^3}$$
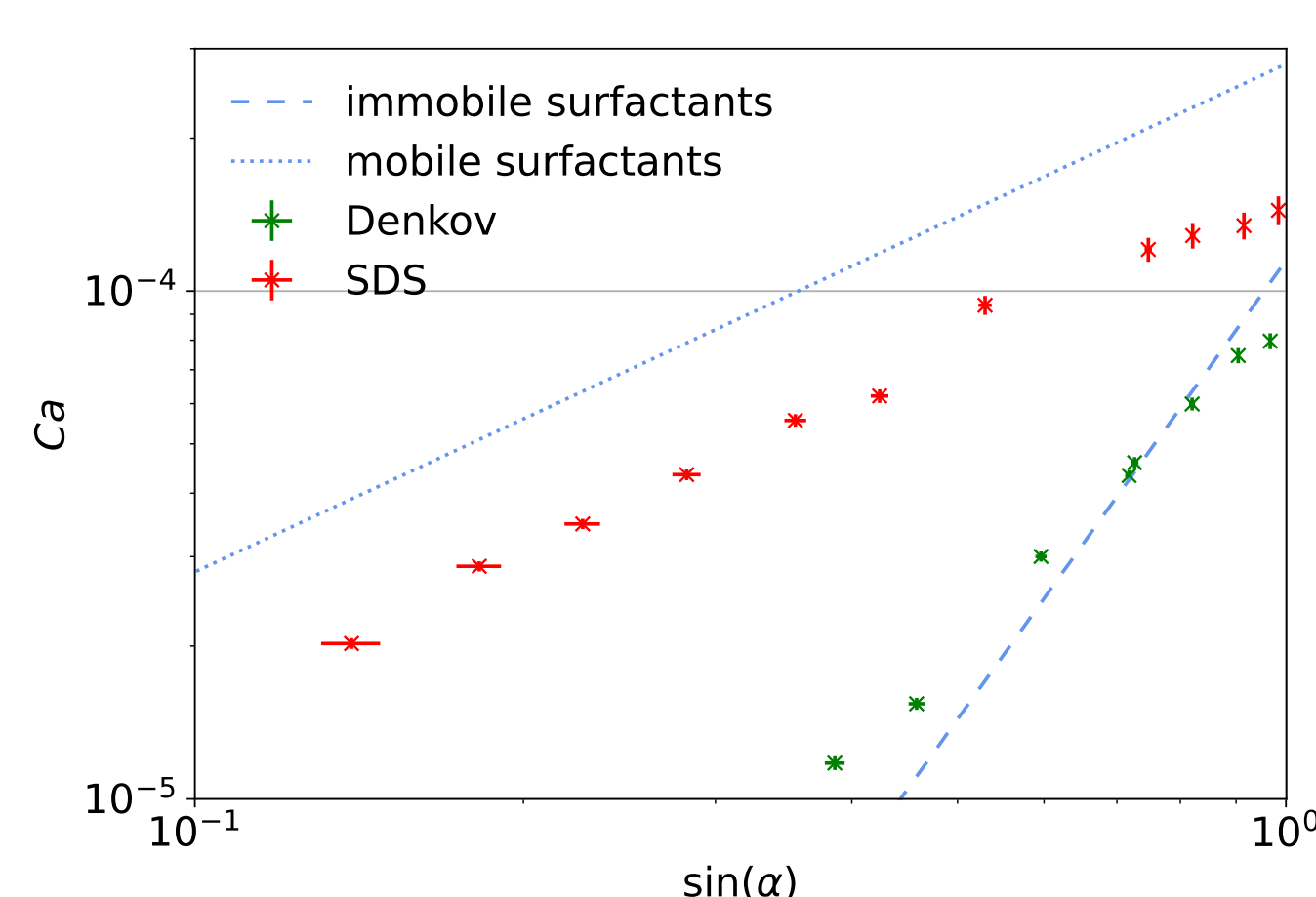
- By measuring the velocity, the dominant force can be determined
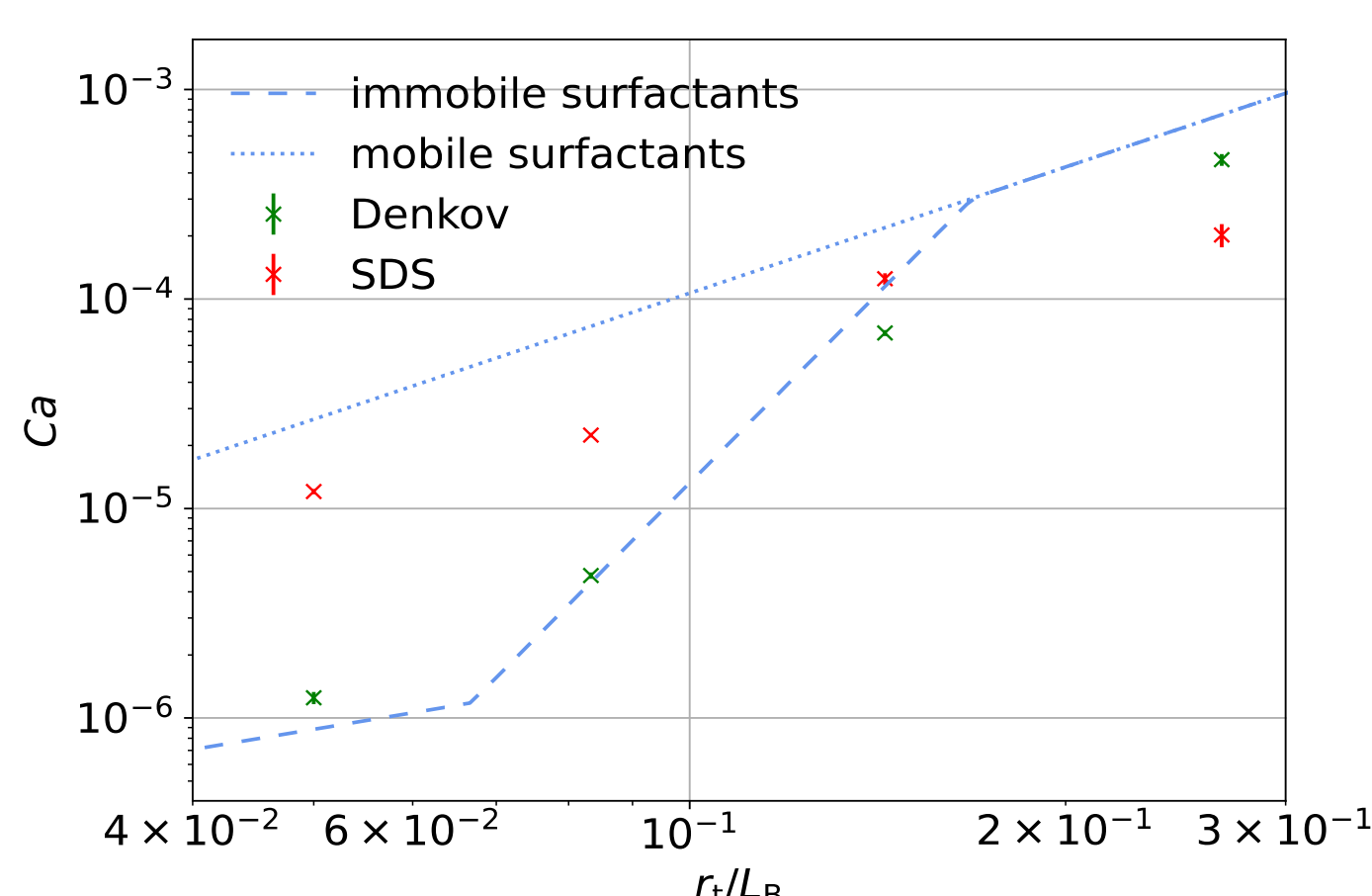
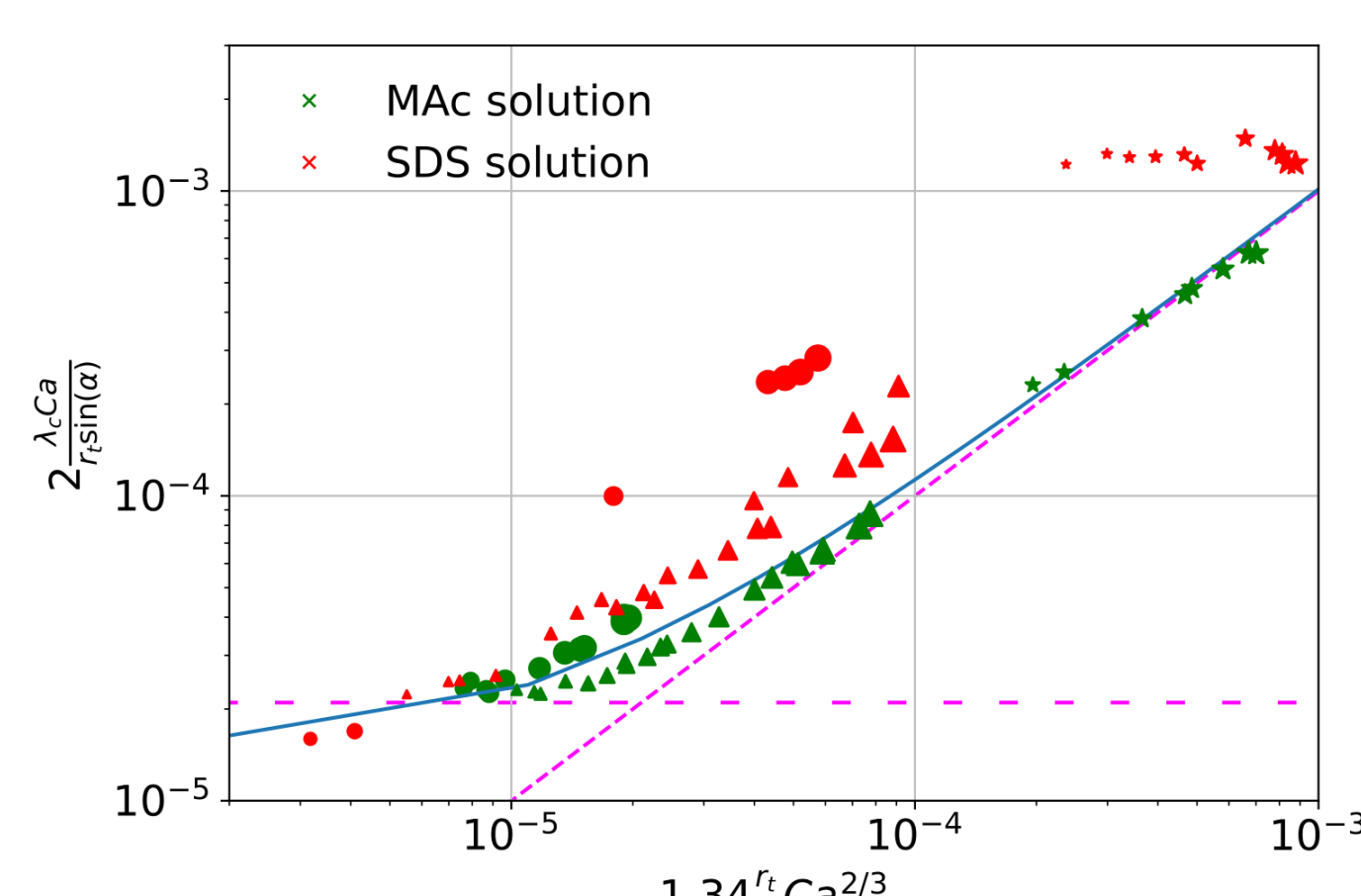## Differences of MAc and SDS solutions

Bubble length dependency
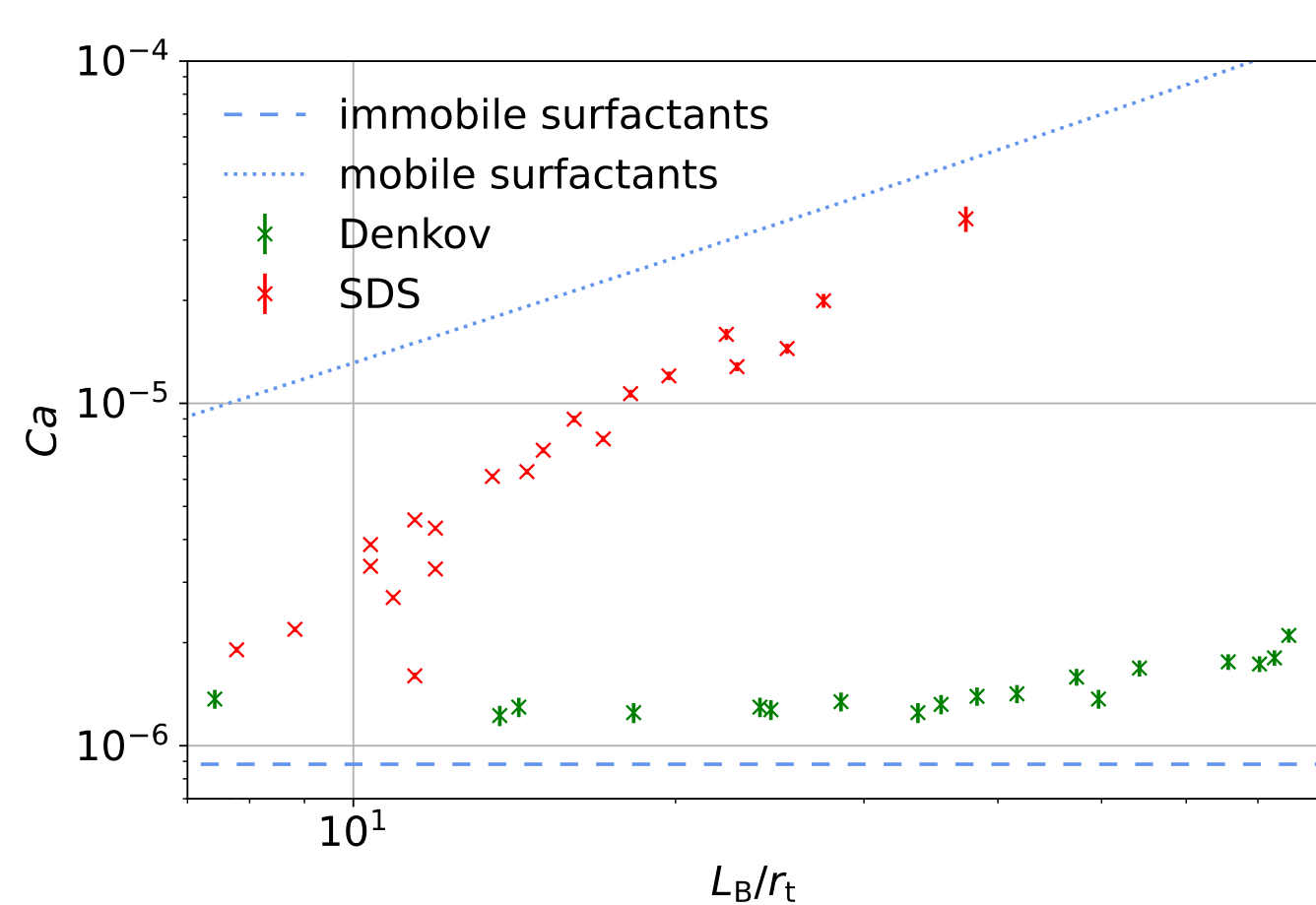
Inclination angle dependency

Tube radius dependency
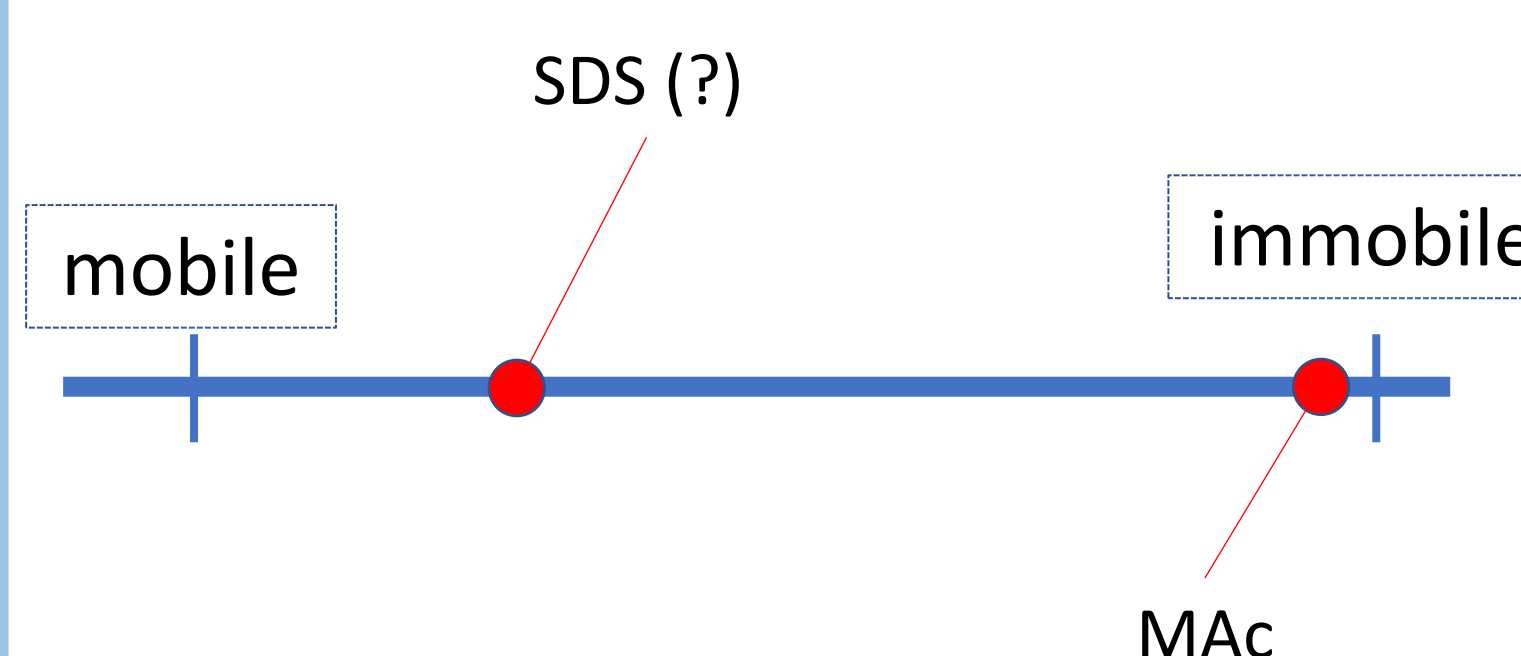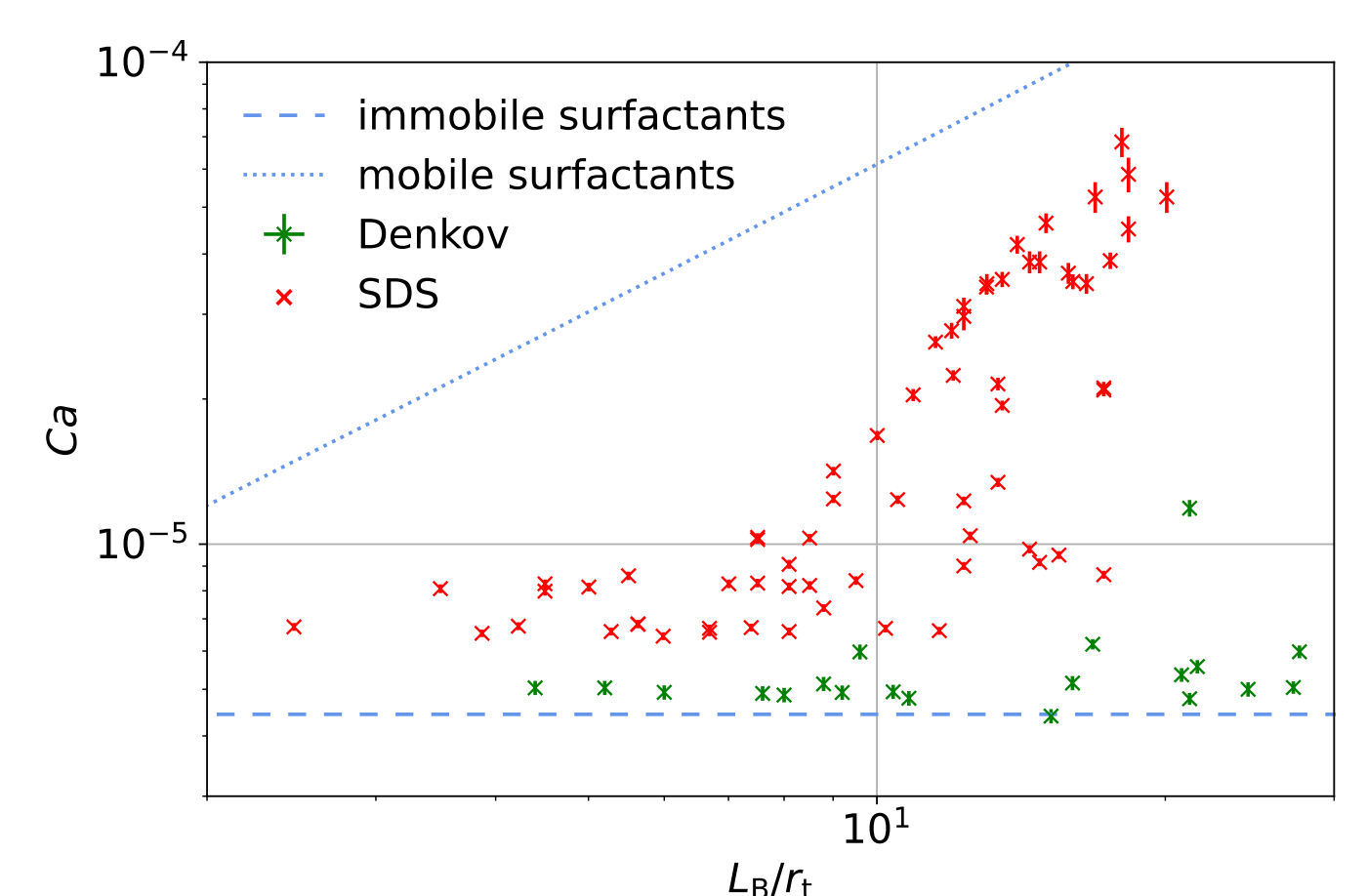
Dimensionless curve of data

- Show characteristic behaviour
- SDS does not fit the model completely

Perspectives

Deviations of SDS
- For low bubble lengths, SDS approached the immobile regime [2]
- Add dodecanol to stabilize surfactant solution

Metrology tool:
- Testing the mobility of a surfactant by measuring bubble rise velocity
- Wider range of surfactants needed as reference (TTAB…)

☞ Examining the hypothesis: SDS is a not completely mobile surfactant showing certain immobile features [2]

References

[1] Cantat, I., 2013b, in Foams: Structure and Dynamics (Oxford University Press)
[2] Denkov, N. D., S. Tcholakova, K. Golemanov, K. P. Ananthpadmanabhan, and A. Lips, 2009, Soft Matter
[3] Dollet, Benjamin, and Christophe Raufaste, 2014, "Rheology of aqueous foams," Comptes Rendus Physique

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