University of Bremen

The Bubble Effect
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Humans on Mars

Simulations of bubble detachment from horizontal surfaces

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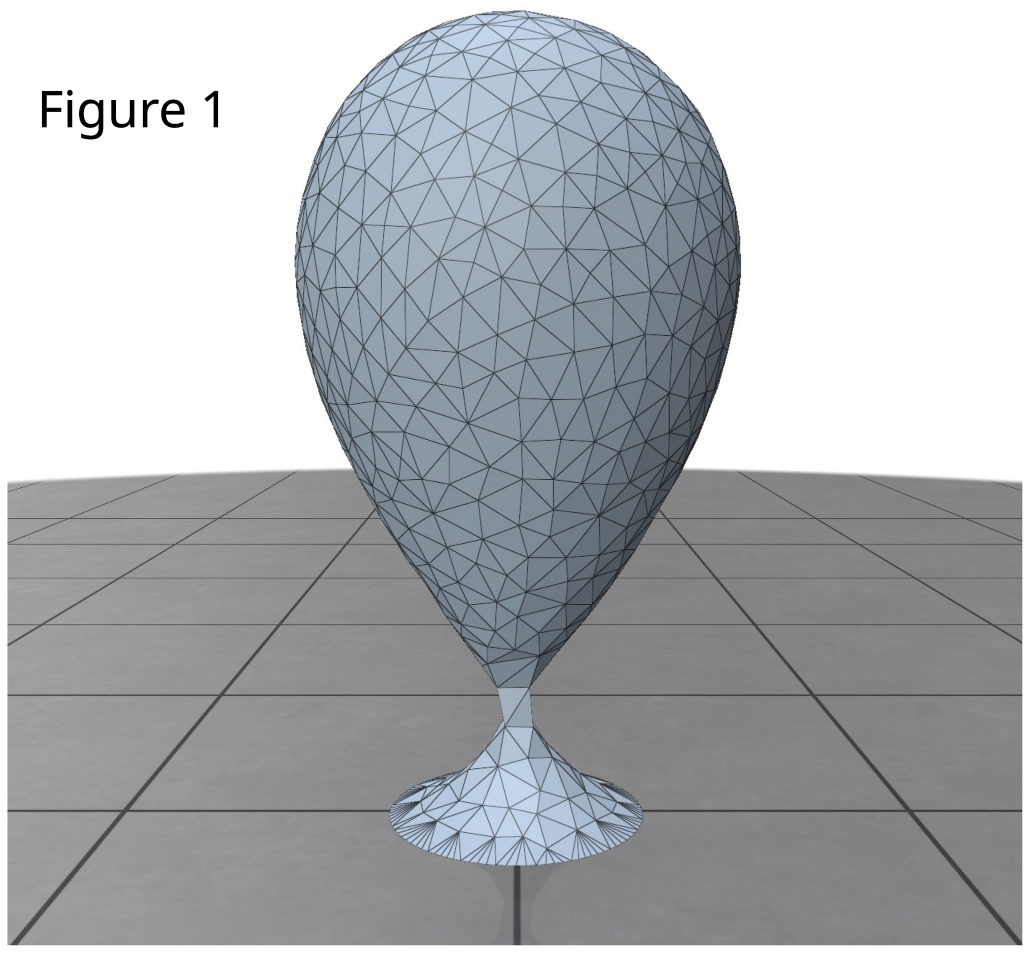
Figure 1



Take Home Message I

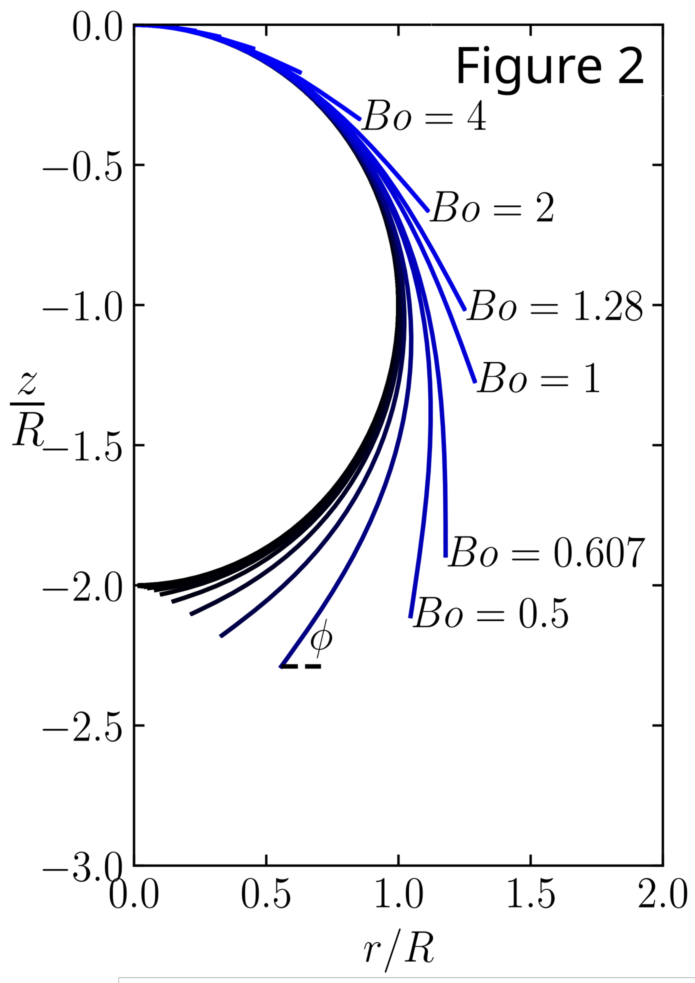
Bubbles detach at maximum radius of 1.2 capillary lengths—smaller cavities enable earlier detachment and improved electrolysis efficiency.

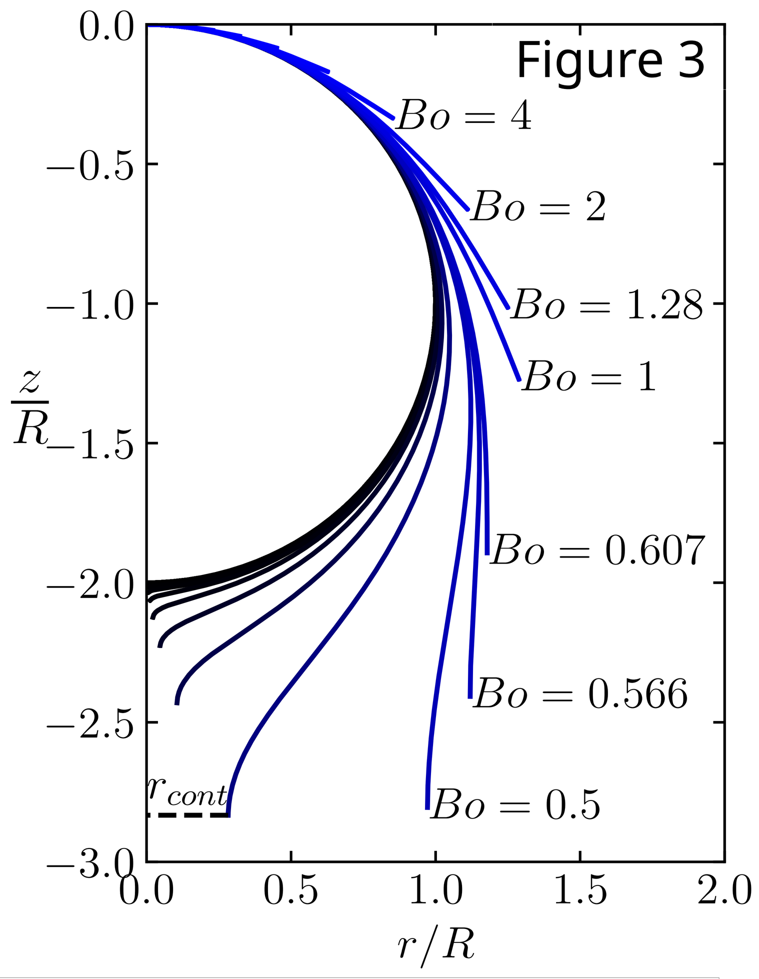
Take Home Message II

Surface geometry controls bubble behavior: pinned contact lines (fixed at cavities) create larger bubbles than spreading contact lines (mobile on smooth surfaces).

Research question

How do surface tension, density and gravity affect the size of bubbles when they detach from a horizontal electrode?

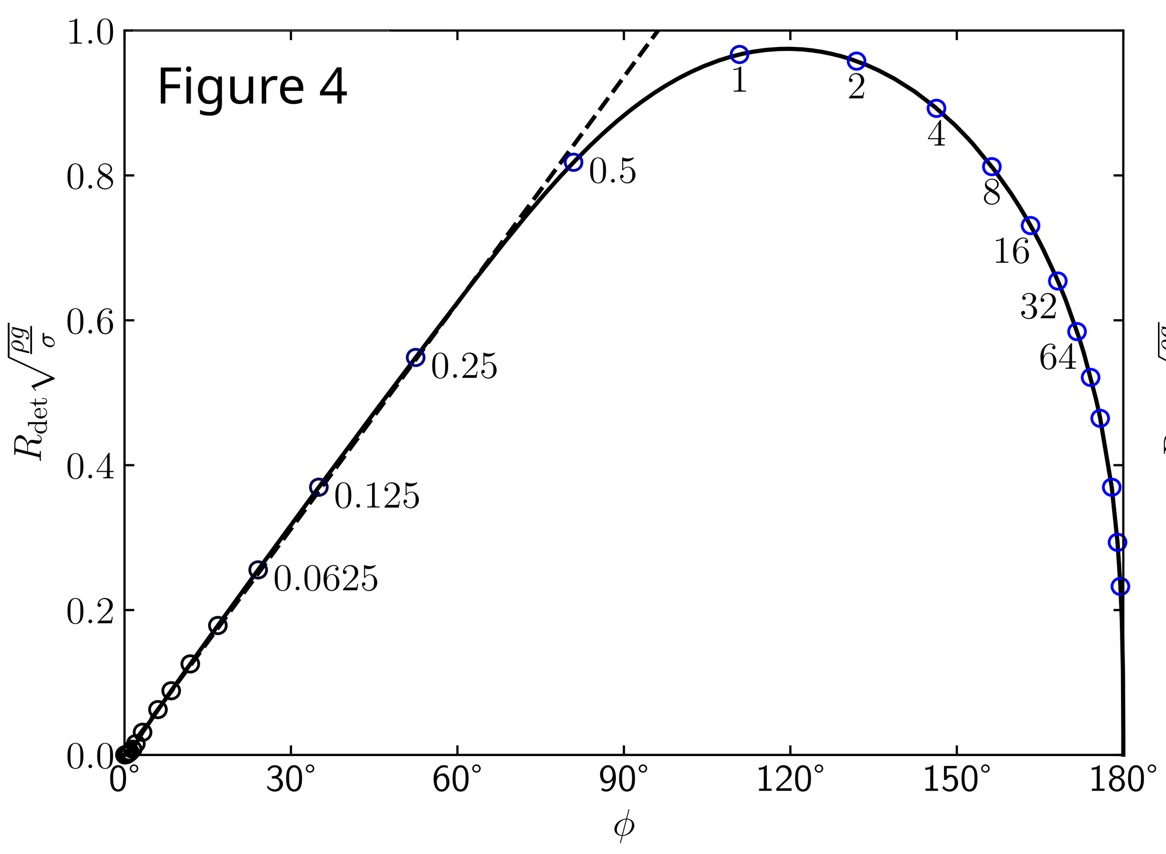


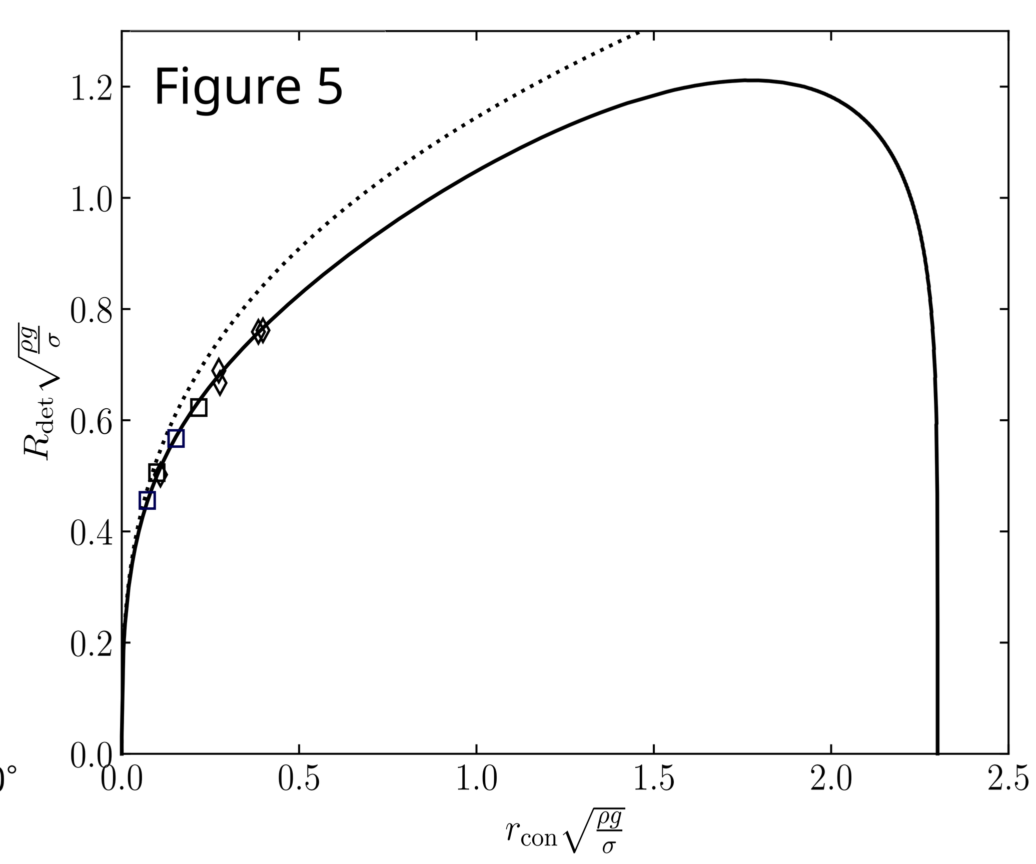


Approach

$$\sigma\left(\frac{d\theta}{ds} + \frac{\sin\theta}{x}\right) = \Delta\rho\, gz - \frac{2\sigma}{R}$$

We solve the Young-Laplace equation (above) for axially symmetric bubbles (Bashforth & Adams, 1883). The **Bond number Bo = $\Delta\rho\, gR^2/\sigma$** characterizes the buoyancy-surface tension balance. We analyze "spreading" bubbles (fig. 2) and "pinned" bubbles (fig. 3) to determine maximum stable sizes (Chesters, 1978).





Results

Fig. 1 Our 3D model of the bubble interface

Fig. 2 The profile of a spreading bubble with contact angle ϕ.

Fig. 3 The profile of a pinned bubble with contact angle radius r.

Figs. 4 & 5 The effect of contact angle ϕ and radius r on detachment radius R.

Fig. 6 Mesh size convergence of the 3D model.

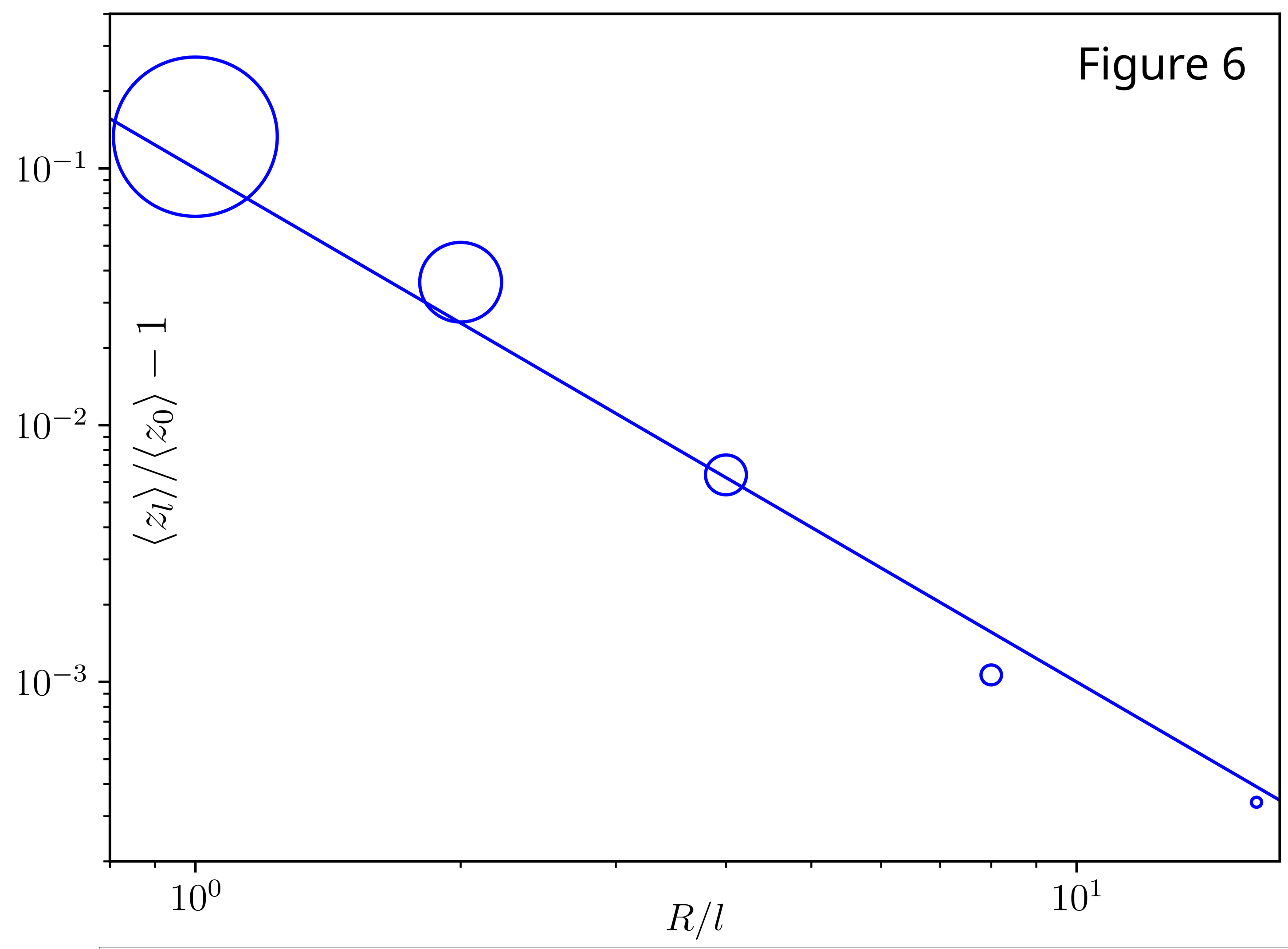
Implications

Maximum detachment size: In figure 4, spreading bubbles detach at contact angle 121° with radius 0.97 capillary lengths. In figure 5, pinned bubbles reach maximum radius ~1.2 capillary lengths, agreeing with carbonated water and boiling experiments (Mori et al., 2001, Lesage et al., 2013).

Critical cavity size: In figure 5, the maximum cavity radius of 2.40 capillary lengths matches predictions of stability analysis (Pitts, 1974).

Heterogeneous surfaces: We are making three-dimensional simulations using the discrete differential geometry method (Endres et al., 2022) of triangulated interfaces over patterned electrodes to determine the effect of surface impurities and chemical heterogeneities on the contact angle at the bubble foot.

Convergence of the 3D model: We obtain a second-order grid convergence of the centre of mass height to the Adams Bashforth (1883) result, enabling us to investigate non-axially symmetric bubbles over electrodes with bumps and impurities.



References

[1] Bashforth & Adams, Cambridge Univ. Press, 1883.

[2] Chesters, Int. J. Multiphase Flow, 1978.

[3] Mori & Baines, Int. J. Heat Mass Transf., 2001.

[4] Lesage & Marois, Int. J. Heat Mass Transf., 2013.

[5] Pitts, J. Fluid Mech., 1974.

Conference contributions

[1] Cannon, I., Endres, S., Mädler, L., & Avila, M. "Bubble detachment from heterogeneous surfaces" EFDC2, Dublin, Ireland, August 27, 2025.

[2] Cannon, I., Endres, S., Mädler, L., & Avila, M. “Bubble detachment in electrolysis” 21st Multiphase Flow Workshop, Dresden, Germany, November 13, 2025

Publications

[1] Cannon, I., Endres, S., Mädler, L., & Avila, M. "Axially symmetric bubble detachment from horizontal surfaces" (prepared for submission to Physical Review Fluids)

[2] Cannon, I., Endres, S., Mädler, L., & Avila, M. "A front tracking method for drops and bubbles under hydrostatic pressure" (prepared for submission to the SIAM Journal on Scientific Computing)

[3] Cannon, I., Morón, D., Vela-Martín, A., & Avila, M. “Strain-driven drop breakup in turbulence” (Submitted to the IOP Journal of Physics on October 27, 2025).