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10. Drop explosion

10. Výbuch kvapky

Tomáš Roch

Faculty of Mathematics Physics and Informatics

Comenius University in Bratislava

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10. Droplet Explosion

When a drop of a water mixture (e.g. water-alcohol) is deposited on the surface of a hydrophobic liquid (e.g. vegetable oil), the resulting drop may sometimes fragment into smaller droplets. Investigate the parameters that affect the fragmentation and the size of the final droplets.

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Entry #V0020

Marangoni Bursting: Evaporation-Induced Emulsification of a Two-Component Droplet

Guillaume Durey[1], Hoon Kwon[1], Julien Mazet[2], Quentin Magdelaine[1], Mathias Kasiulis[1], Ludovic Keiser[3], Hadrien Bense[3], Pierre Colinet[4], José Bico[3], Étienne Reyssat[3]

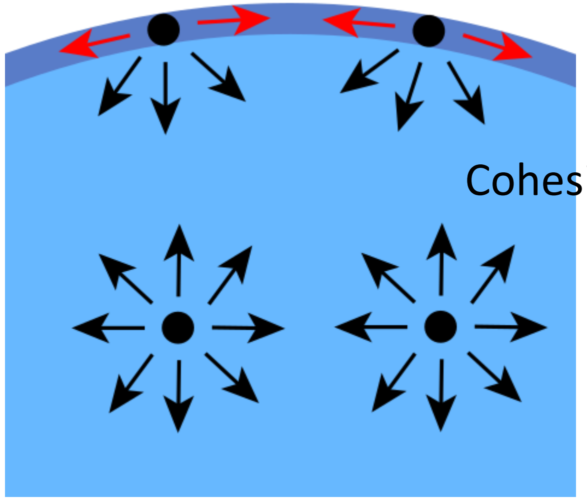
1 The Lutetium Project, ESPCI Paris, PSL Research University, youtube.com/thelutetiumproject
2 Conservatoire National Supérieur de Musique et de Danse de Paris, PSL Research University
3 Laboratoire PMMH, CNRS, ESPCI Paris, PSL Research University, Sorbonne Université, Université Paris Diderot
4 Transferts, Interfaces et Procédés, Université Libre de Bruxelles

https://www.youtube.com/watch?v=y44rQdiixuw

Surface tension γ

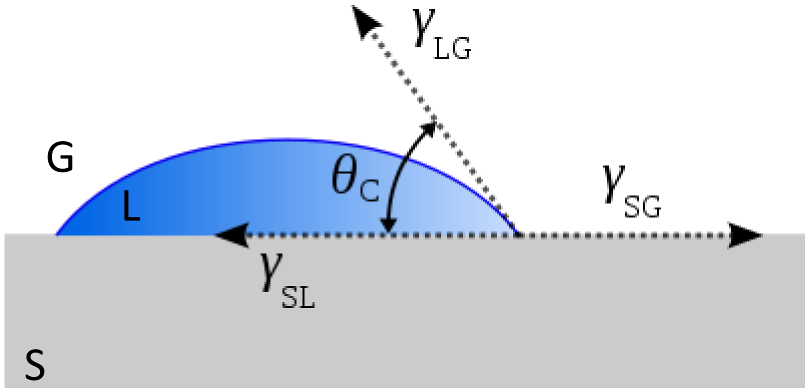
[N/m] , [J/m2]

Important in capillarity



https://en.wikipedia.org/wiki/Surface_tension

Hydrophobicity γ >90°



$$\gamma_{SG} = \gamma_{SL} + \gamma_{LG} \cos \theta$$

θ – contact angle

Plateau–Rayleigh instability

Fluid stream breaks up into smaller drops with less surface area

Young – Laplace equation

$$\Delta p = \gamma \left(\frac{1}{R_x} + \frac{1}{R_y} \right)$$

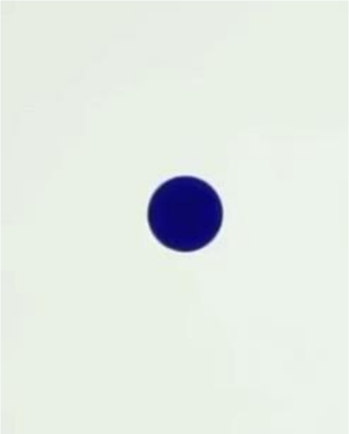
Δp – Laplace pressure

$R_{x,y}$ – radii of curvature of surface

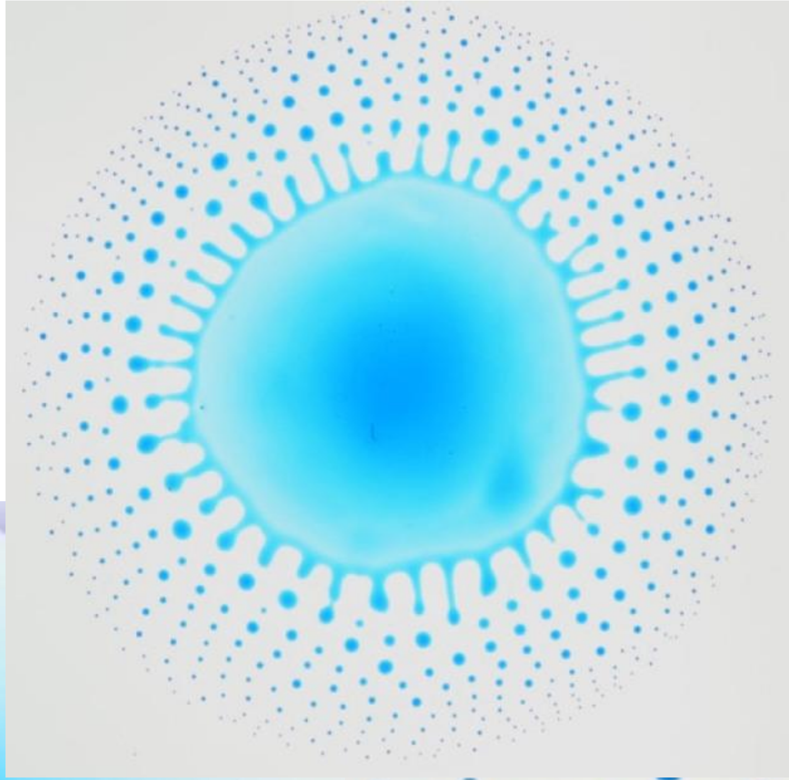
Marangoni effect/flow

The mass transfer along an interface between two fluids due to a gradient of the surface tension.
The surface tension gradient can be caused by concentration gradient or by a temperature gradient.
Liquid with a high surface tension pulls more strongly on the surrounding liquid

Pure water drop in oil



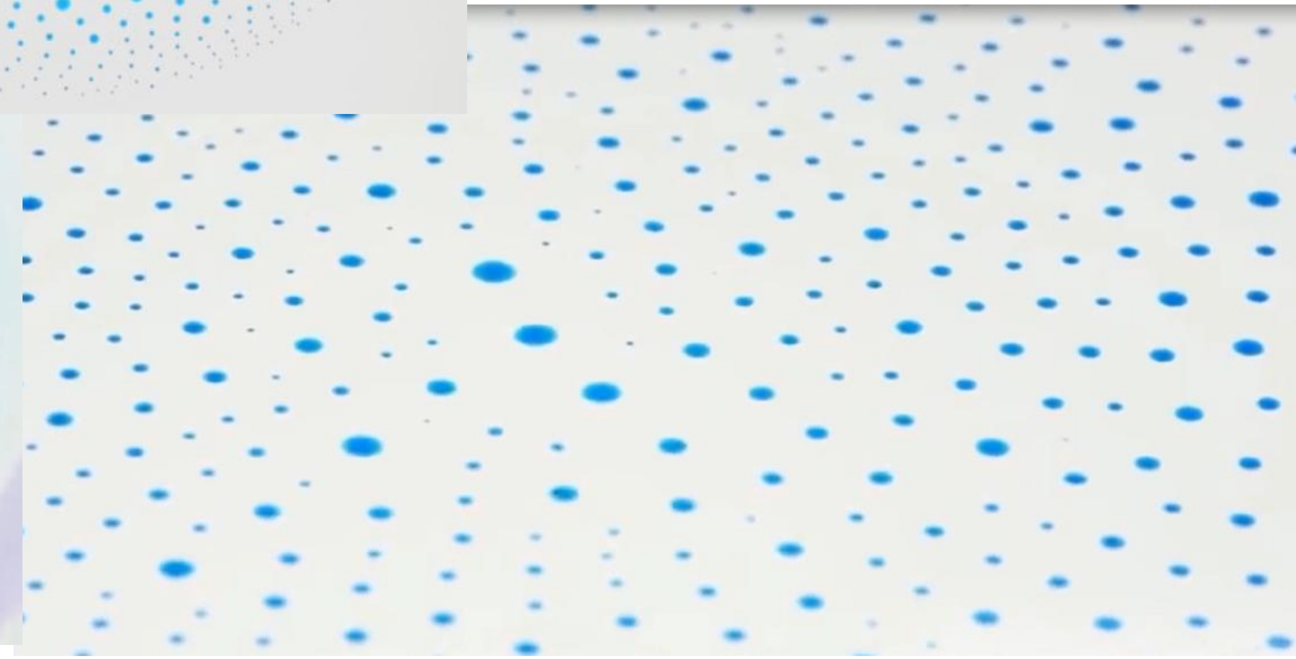
Alcohol/water > 0.3



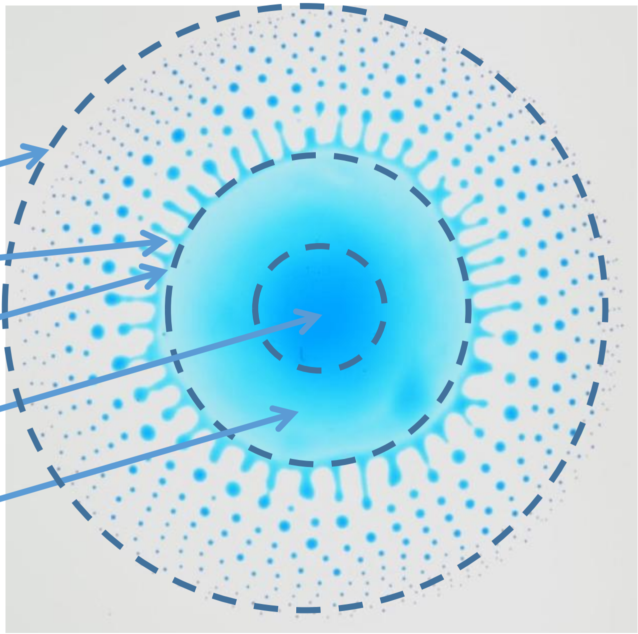
After longer time droplets size decreases and droplets agglutinate into clusters

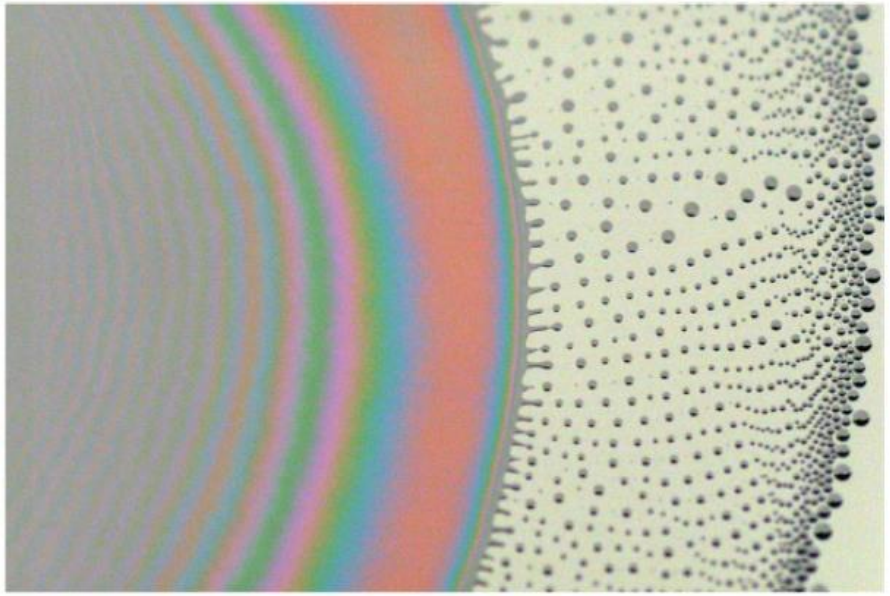
Alcohol in oil

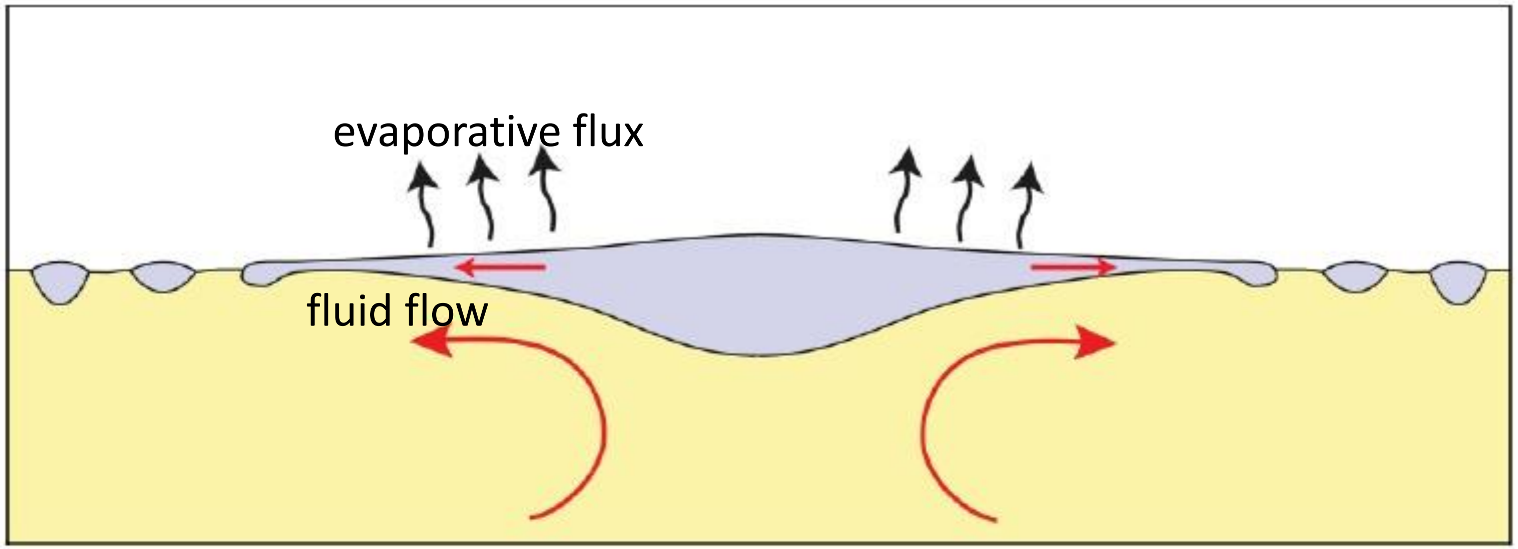
Final droplets



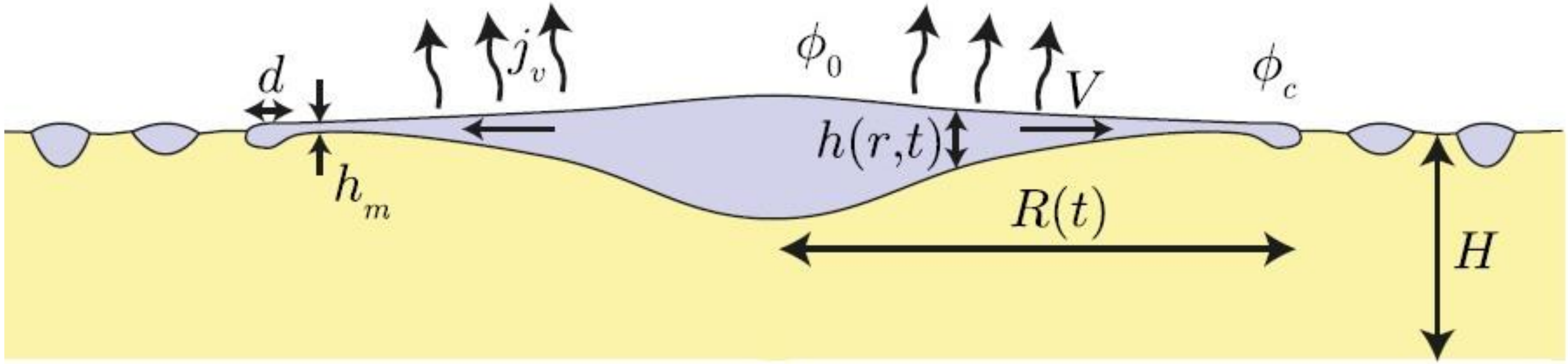
evaporation rate of alcohol >> water





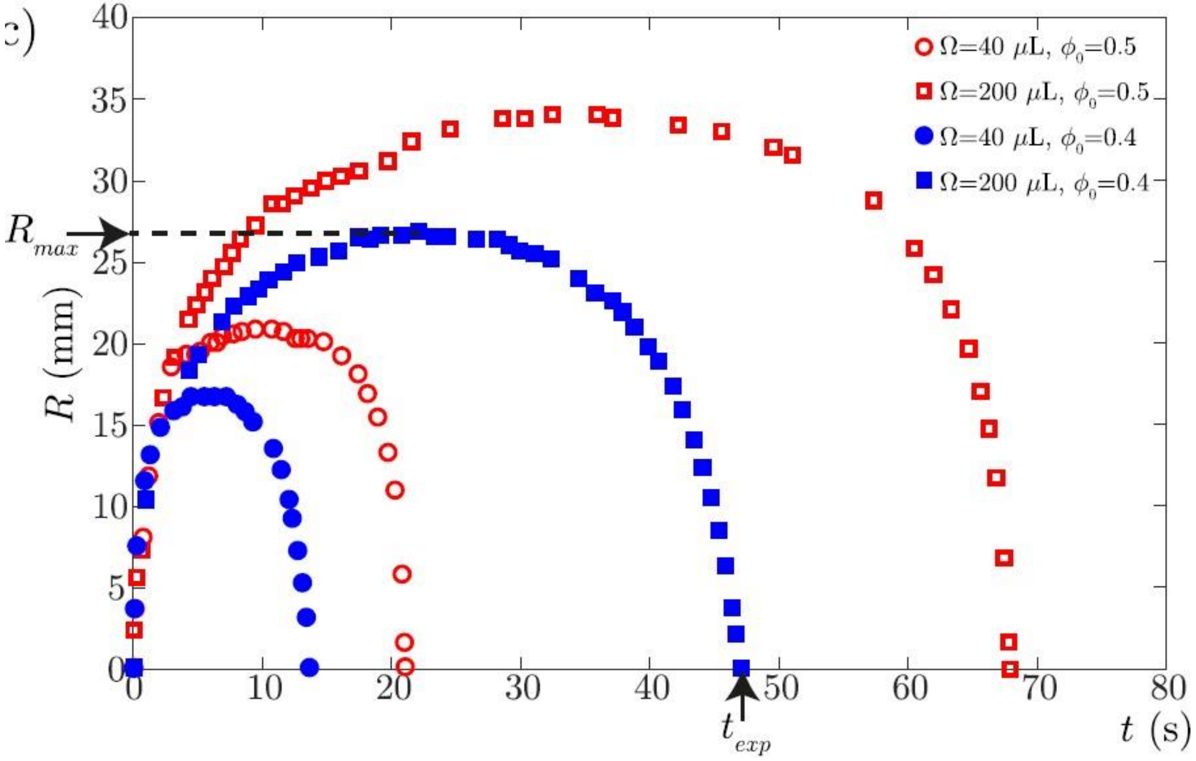


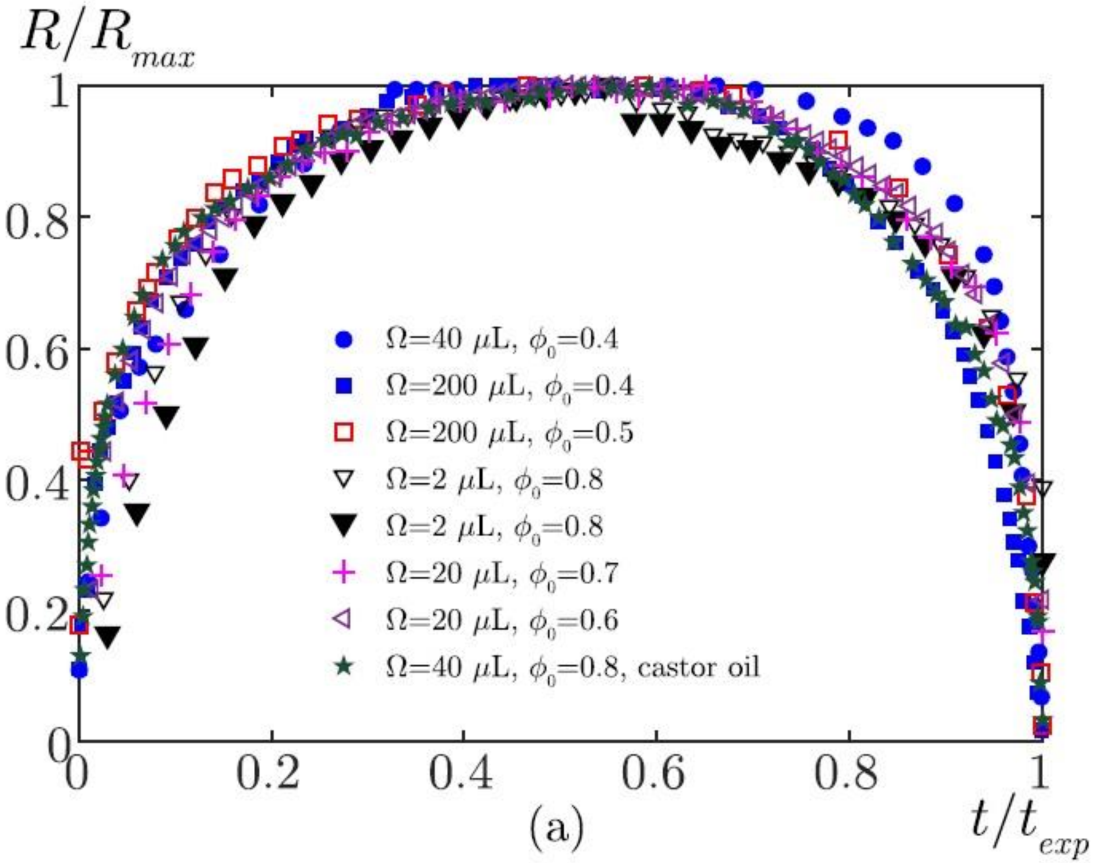
Keiser, L., Bense, H., Colinet, P., Bico, J., Reyssat, E., 2017. Marangoni Bursting: Evaporation-Induced Emulsification of Binary Mixtures on a Liquid Layer. Physical Review Letters 118.. doi:10.1103/physrevlett.118.074504



self-similarity of the spreading dynamics R(t)

Scaling law





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characteristic radius and time scale

$$R^* \sim \left(\frac{(\phi_0 - \phi_c)\Delta\gamma H \Omega_0}{(1-\phi_c)\eta_o j_v} \right)^{1/4}$$

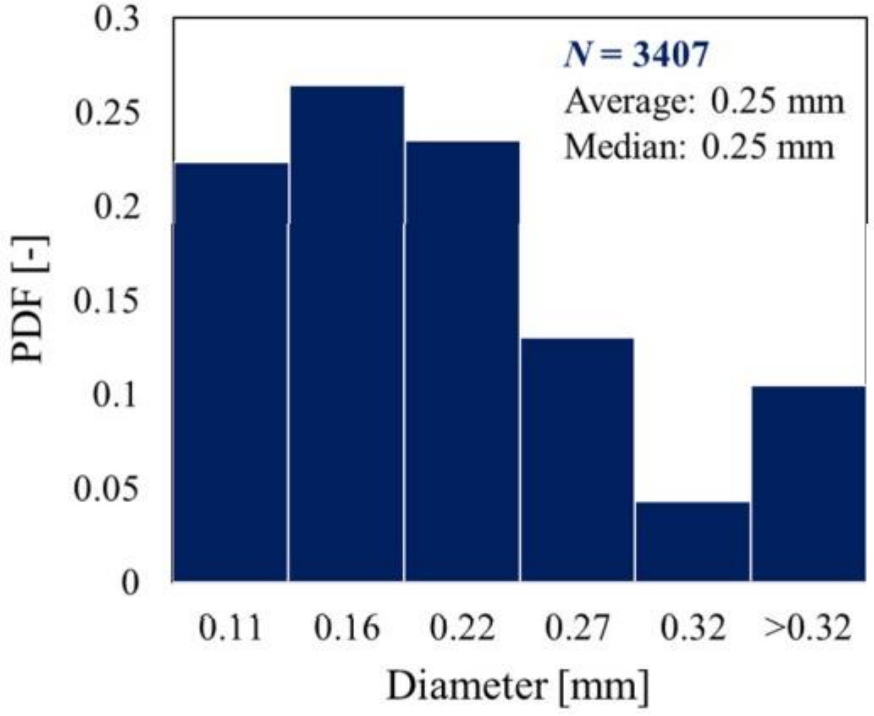
$$\tau \sim \left(\frac{(\phi_0 - \phi_c)\eta_o \Omega_0}{(1-\phi_c)\Delta\gamma H j_v} \right)^{1/2}$$

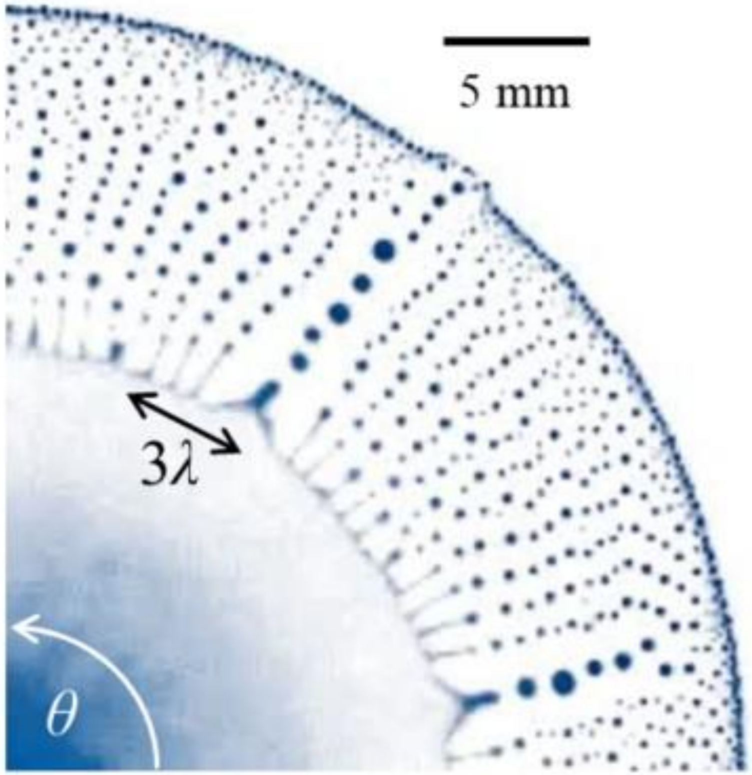
ϕ_0	Initial alcohol concentration
H	Maximum droplet thickness
Ω_0	Initial volume
γ	Effective tension
η_o	Viscocity constant
j_v	Evaporation constant
ϕ_c	Critical concentration (0.35+/-0.2)

Keiser, L., Bense, H., Colinet, P., Bico, J., Reyssat, E., 2017. Marangoni Bursting: Evaporation-Induced Emulsification of Binary Mixtures on a Liquid Layer. Physical Review Letters 118.. doi:10.1103/physrevlett.118.074504

Test sample	Density ρ (kg/m^3)	Dynamic viscosity ν (mm^2/s)	Surface tension σ (mN/m)
Water[32]	997	0.89	72
Ethanol[32]	785	1.37	22
IPA[32]	781	2.61	21
Sunflower oil	916	58	32 (Ref. 21)
Silicone oil[33] (1000 cSt)	970	1000	21

Final droplets size distribution





Capillary length of liquid-liquid (IPA-oil) interface:

$$\lambda_c \sim \sqrt{\frac{\gamma_{so}}{(\rho_o - \rho_s)g}},$$

~ 1.5 mm (for γ_{SO} = 3 mN/m, ρ_o=9.16g/cm^3 ρ_a=7.81g/cm^3, g=9.81m/s^2.

Fragmentation period 0.65 .. 2.2mm

[K.Hasegawa, Y. Manzaki, Phys. Fluids **33**, 034124 (2021); https://doi.org/10.1063/5.0041346]

Experimental parameters

Initial concentration of alcohol in water solution ϕ_0
Temperature (room, elevated 90°C)
Initial drop size

Experimental setup

Flat and wide Petri dish – oil level few mm
Pipete for droplet injection
Cell phone with suitable camera resolution
For higher alcohol content and resulting small drops microscope optics or magnifying lens needed
Desinfection alcohol, IPA, ethanol, + food color, (red wine)
For better visualization and tracking of the fluid movement use some fine particle powder deposit on the drop surface

SW: ImageJ – for droplets analysis: https://imagej.nih.gov/ij/
https://imagej.nih.gov/ij/docs/pdfs/examples.pdf
https://physlets.org/tracker/

https://journals.aps.org/prfluids/abstract/10.1103/PhysRevFluids.3.100501
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https://www.researchgate.net/publication/313835093_Marangoni_Bursting_Evaporation-Induced_Emulsification_of_Binary_Mixtures_on_a_Liquid_Layer