Morphology of surfactant-free and surfactant-laden droplets in homogeneous isotropic turbulence

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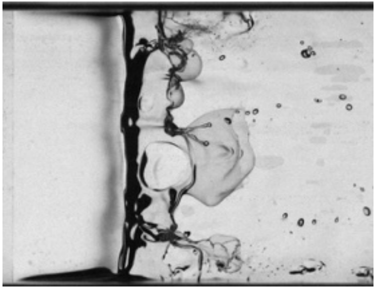
We care about droplet morphology

CO_2 absorption (Merlivat & Memery, 1983)

Credit: Linda Gietka

Droplet breakup during cough



Kant et al., 2023

What is the morphology of droplets in turbulence?

How do surfactants affect morphology?

Numerical method

We use the in-house solver *Fujin*. Fluid motion,

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla \cdot \left[\mu \left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right)\right] + \nabla \cdot (\tau_c f_\sigma) + \mathbf{f}_\mathbf{s}, \tag{1}$$

$$\nabla \cdot \mathbf{u} = 0, \tag{2}$$

Droplet motion (Ii et al., 2012)

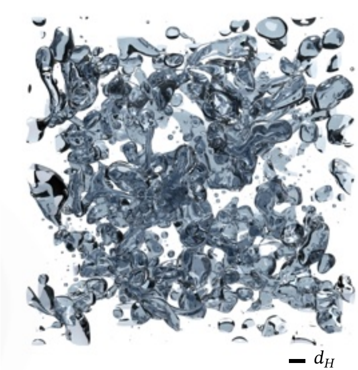
$$\frac{\partial \phi}{\partial t} + \nabla \cdot (\mathbf{u} H) = 0, \tag{3}$$

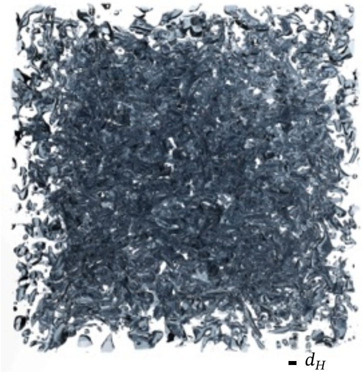
Surfactant motion (Engblom et al., 2013)

$$\frac{\partial \psi}{\partial t} + \mathbf{u} \cdot \nabla \psi = \nabla \cdot (M_\psi \nabla \mu_\psi), \tag{4}$$

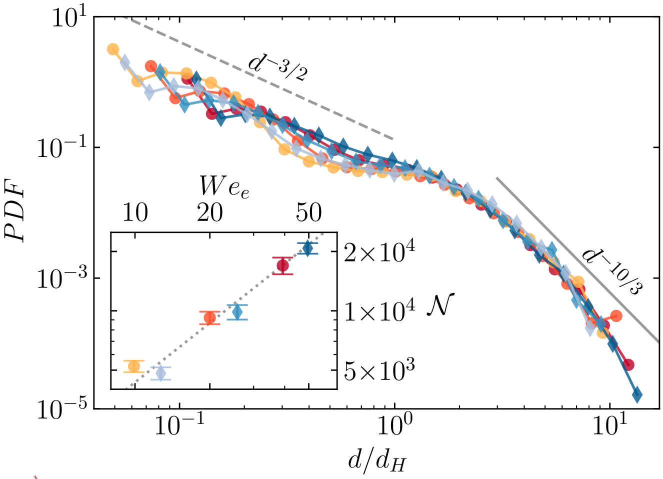
Simulation setup

- Tri-periodic domain with 500^3 grid points.
- Six simulations with three values of surface tension, and two surfactant concentrations.





- Hinze-scale $d_H \equiv 0.725\langle\sigma\rangle_I^{3/5}\rho^{-3/5}\epsilon^{-2/5}$ (Hinze, 1955).



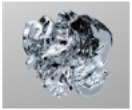
- Surface tension ↓, number of droplets ↑.
- Define an equivalent diameter for each droplet, $d \equiv (6V/\pi)^{1/3}$.
- $d < d_H$: coalescence.
- $d > d_H$: breakup (Deane & Stokes, 2002).

←1.0→

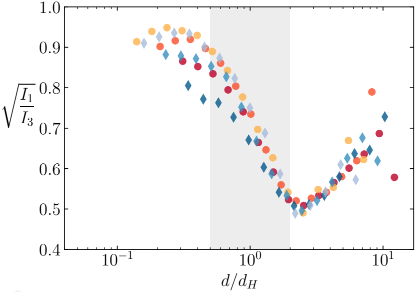
↑ 0.9 ↓

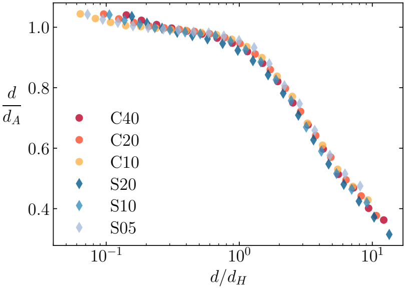
←1.0→

↑ 0.5 ↓



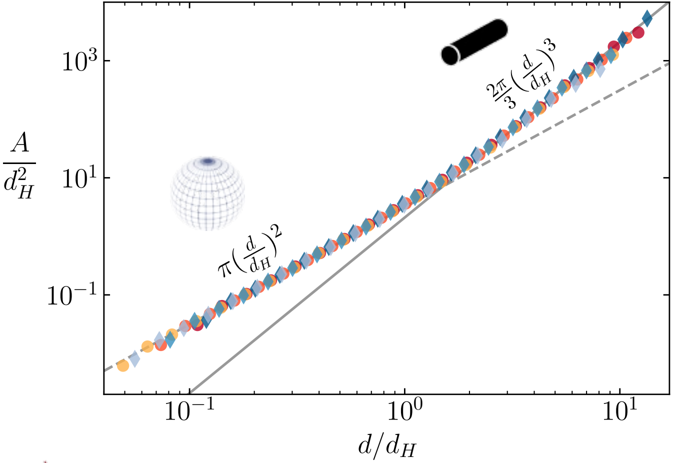
Aspect ratio $\sqrt{I_1/I_3}$	0.946	0.633	0.905
Sphericity d/d_A	0.999	0.965	0.701





- $d << d_H$ aspect ratio → 1.
- $d \approx d_H$ droplets are extended.
- $d >> d_H$ aspect ratio → 1.
- $d > d_H$ area ↑.

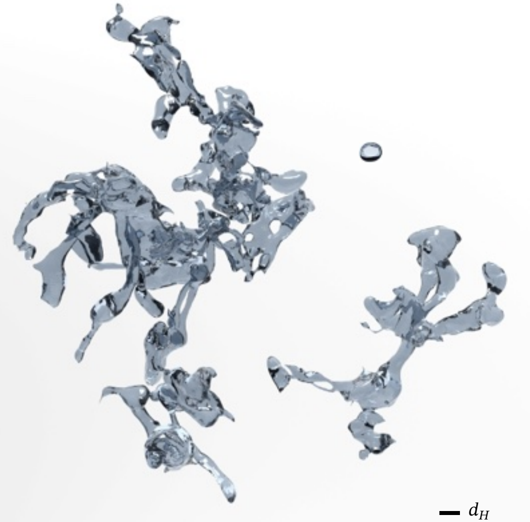
What is the area of the droplets?



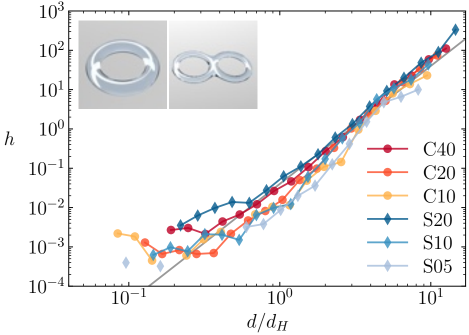
- $d < d_H$: spheroids.
- $d > d_H$: filaments with diameter d_H.

Aspect ratio and sphericity

- The large droplets are filamentous.
- Aspect ratio → 1 implies the filaments must be coiled.

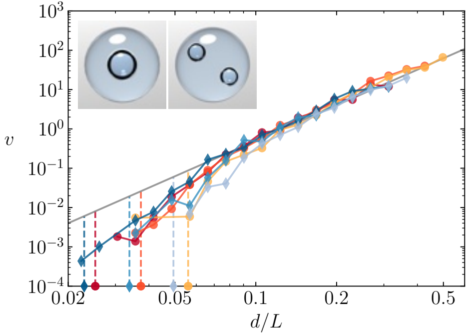


How many handles and voids are there?



$$h = 0.04(d/d_H)^3$$

- Constant number of handles per unit length of filament.

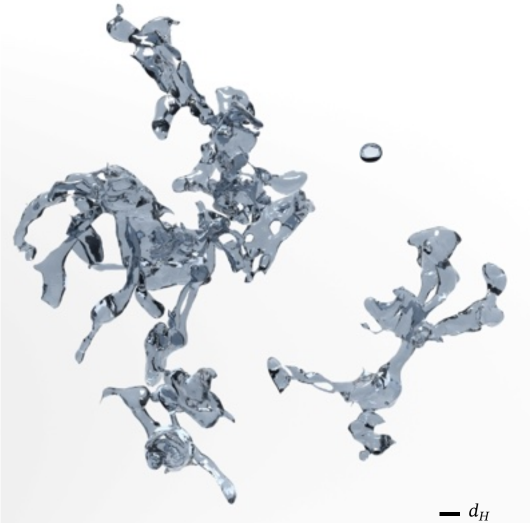


$$v = 500(d/L)^3$$

- Constant number of voids per unit volume of droplet.

Conclusions

- Surfactant effects can be described by a reduction of the surface tension.
- Average surface tension can be used to define the Hinze scale d_H in surfactant-laden flows.
- Droplets smaller than d_H are spheroidal.
- Droplets larger than d_H are filamentous.
- Cannon, I., Soligo, G., & Rosti, M. E. (2023). Morphology of clean and surfactant-laden droplets in homogeneous isotropic turbulence. *arXiv:2307.15448*



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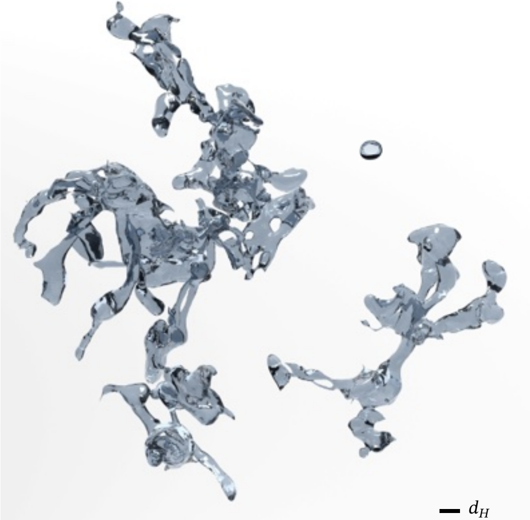
I am looking for a postdoctoral position, email me ianto.cannon@gmail.com

Thank you!



How to count the number of handles?

We compute the Euler characteristic $\chi = n - e + f$ of the droplet interfaces.

$\chi = 0$ $\qquad$ $\chi = 2$ $\qquad$ $\chi = 4$

This gives the number of handles h and voids v. $\chi = 2 + 2v - 2h$.