Direct numerical simulations of surfactants in bubbly turbulent flows

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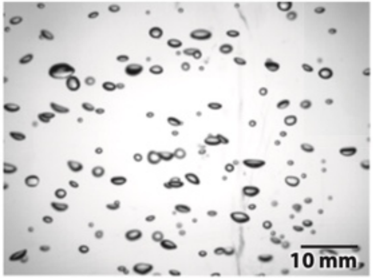
OIST

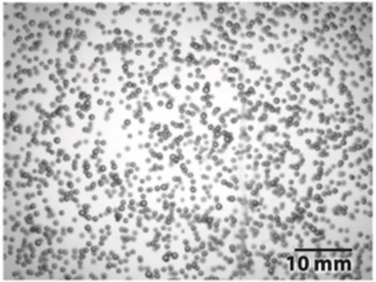
Ianto Cannon, Giovanni Soligo, and Marco E. Rosti,
Complex Fluids and Flows unit, Okinawa Institute of Science and Technology

Introduction

"The **coalescence** of small bubbles hardly occurs in the presence of surfactant"[1].



Bubbles in tap water.

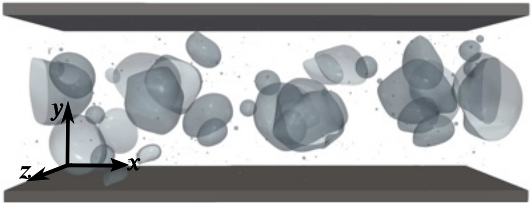


Bubbles in tap water with 2ppm Triton X-100 solution.

[1] Takagi & Matsumoto 2011 *Annual Review of Fluid Mechanics* 43, 615–636

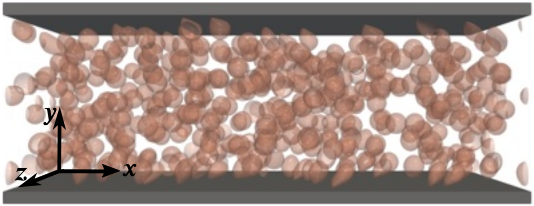
Geometry 1: Bubbles in channel flow

Friction Reynolds number	$Re_\tau \equiv u_\tau L/\nu = 180$
Four volume fractions	$\Phi = 0\%,\ 2.5\%,\ 5\%,\ 10\%,$
Two values of surface tension	$We_\tau \equiv \rho_c u_\tau^2 L/\gamma = 0.57,\ 1.14$



Bubbles are modelled using the **volume of fluid** (VOF) method[2], allowing **easy coalescence and breakup**.

[2] Unverdi & Tryggvason 1992 *Journal of Computational Physics* 100, 25–37.

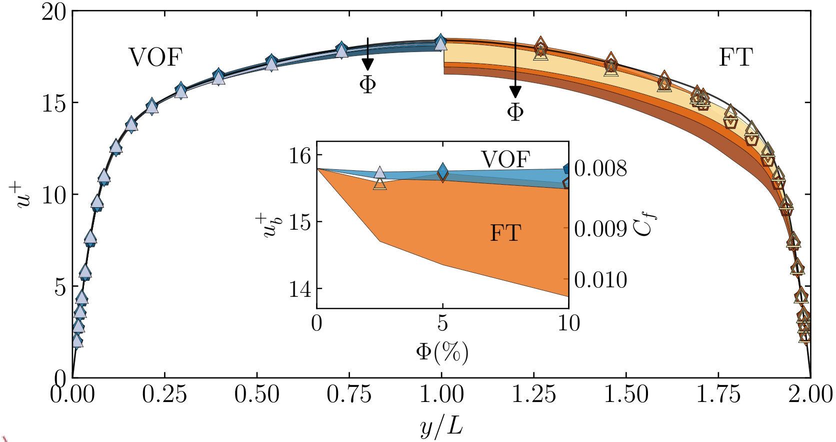


Bubble interfaces are modelled using the **front tracking** (FT) method[3]. **No coalescence or breakup** occurs.

[3] Ii, Sugiyama, Takeuchi, Takagi, Matsumoto & Xiao 2012 *Journal of Computational Physics* 231, 2328–2358.

Flow profile

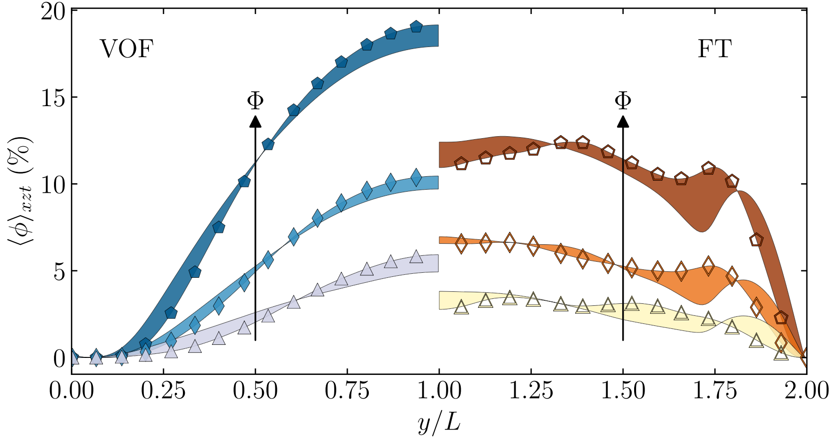
As the volume fraction of bubbles increases, the **flow rate is reduced**.
Non-coalescing bubbles have a much greater effect.

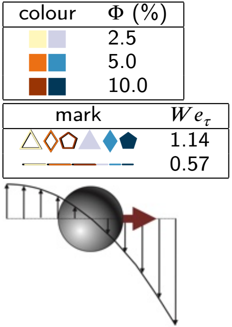


colour	Φ (%)
	2.5
	5.0
	10.0

mark	We_τ
	1.14
	0.57

Volume fraction of dispersed phase





Martel & Toner 2014 Ann. Rev. of Bio. Eng. 16, 371–396

Volume of fluid bubbles are able to coalesce and move to a region of low shear[4].

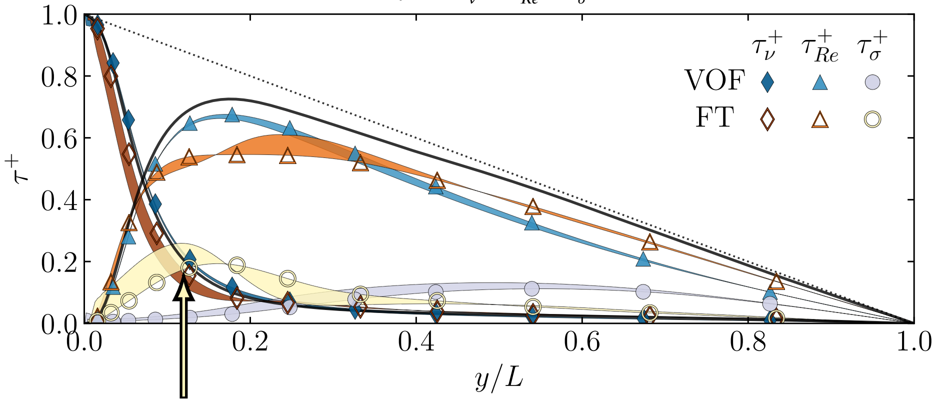
Front tracking bubbles experience a **shear-gradient lift force**, pulling them toward the wall.

[4] Alghalibi, Rosti & Brandt 2019 Phy. Rev. Fluids, 4(10):104201

Shear stresses

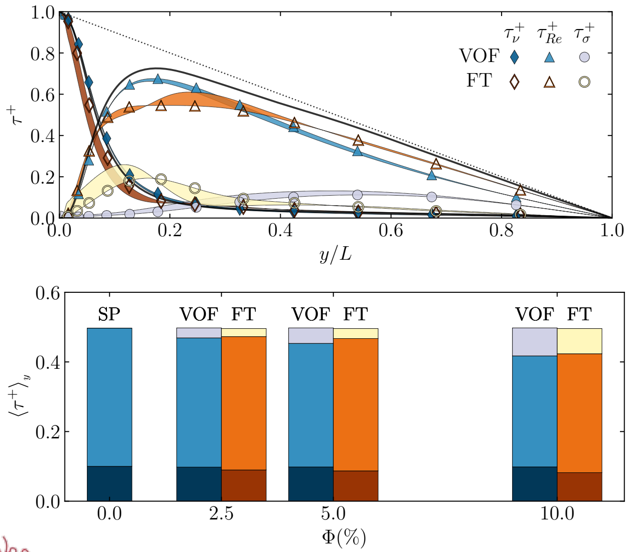
The shear stress is a sum of the viscous, inertial, and surface tension parts,

$$1 - y/L = \tau_\nu^+ + \tau_{Re}^+ + \tau_\sigma^+ \tag{1}$$



The front tracking **surface tension stress** has a peak near the wall.

Shear stresses



The mean viscous shear stress is reduced in the front tracking simulations.
This stress is proportional to the centreline velocity,

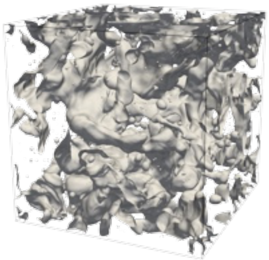
$$\langle \tau_\nu^+ \rangle_y = \frac{1}{L}\int_0^L \frac{du^+}{dy^+}dy = \frac{\delta_\nu}{L}u_{cen}^+. \qquad (2)$$

Hence the flow velocity is reduced in the front tracking simulations.

Geometry 2: Bubbles in tri-periodic flow

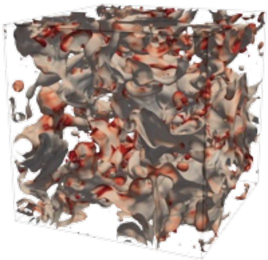
Flow is sustained by stochastic homogeneous isotropic forcing at the large scales[4].
Taylor Reynolds number $Re_\lambda \approx 190$
Surfactant modelled as a third fluid phase, which modifies the surface tension according to the Szyszkowski equation[5]

Clean bubbles



$\phi = 25\%$
$\psi = 0\%$

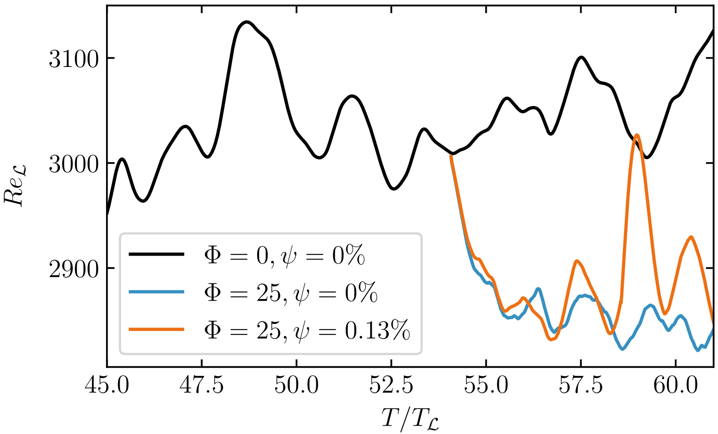
Surfactant-laden bubbles

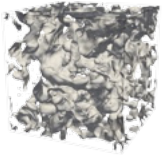


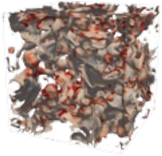
$\phi = 25\%$
$\psi = 13\%$

[4] Eswaran & Pope 1988 *Computers & Fluids*, 16, no. 3, pp. 257–278
[5] Soligo, Roccon and Soldati 2019 *Journal of Computational Physics*, vol. 376, pp. 1292–1311.

Turbulence at the integral length scales

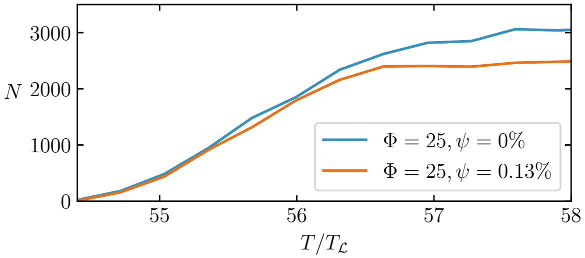




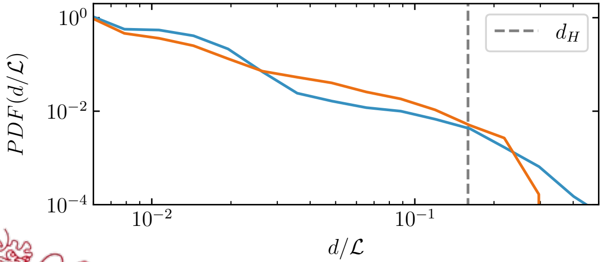


The integral scale Reynolds number $Re_{\mathcal{L}} \equiv U_{RMS}\mathcal{L}/\nu$, is suppressed by the addition of bubbles.

Bubble sizes



N = total number of bubbles.
$T_{\mathcal{L}}$ = integral timescale

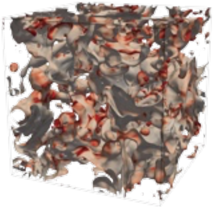


d = droplet diameter
d_H = Hinze scale[4]

The probability density function (PDF) is narrowed by the presence of surfactant.

[4] Hinze 1955 *AIChE J.* vol. 1, no. 3, pp. 289–295.

Conclusions & future work



1. Non-coalescing bubbles produce a significant **drag increase** compared to coalescing bubbles.
2. The non-coalescing bubbles experience a **shear-gradient lift force**, which attracts them to the viscous sublayer in the channel.
3. This leads to large surface tension stresses near the channel wall, **reducing the budget for viscous stress**, and increasing drag.
4. Surfactants **stabilise the droplet distribution** at intermediate sizes

Thank you! Questions?

I. Cannon, D. Izbassarov, O. Tammisola, L. Brandt, and **M. E. Rosti**, *The effect of droplet coalescence on drag in turbulent channel flows*, Physics of Fluids, 33.8, p85112, Aug. 2021, 10.1063/5.0058632.