Coalescence and drag in bubbly channel flows

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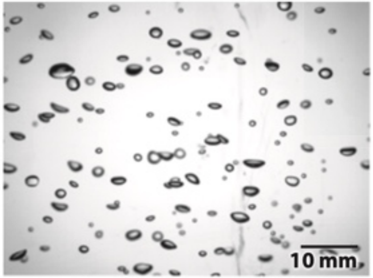
Ianto Cannon, supervised by Marco E. Rosti,
Complex Fluids and Flows unit

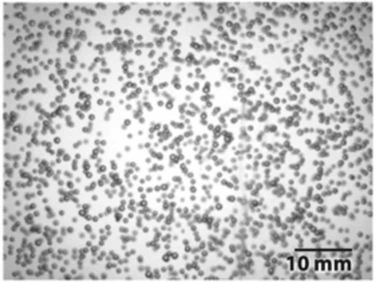
OKINAWA INSTITUTE OF SCIENCE AND TECHNOLOGY GRADUATE UNIVERSITY
沖縄科学技術大学院大学

Introduction

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



Bubbles in tap water.



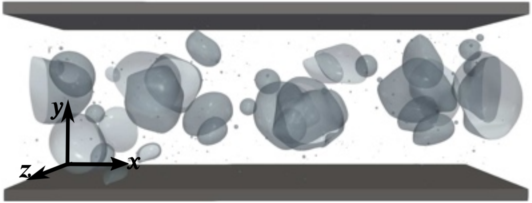
Bubbles in tap water with 2ppm Triton X-100 solution.

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

Methods

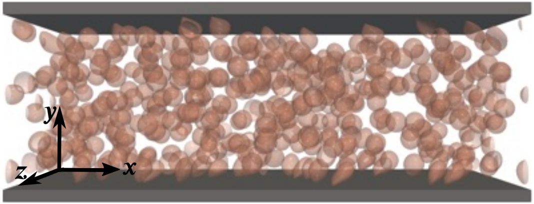
In the **volume of fluid** (VOF) method, an indicator function H is advected with the fluid,[2]

$$\frac{\partial H}{\partial t} + \mathbf{u} \cdot \nabla H = 0. \qquad (1)$$



In the **front tracking** (FT) method, the velocity of the interface is a sum over fluid velocities at nearby grid points,[3]

$$\mathbf{u}^{(l)} = \sum_i D(\mathbf{x}_i - \mathbf{x}^{(l)})\mathbf{u}_i. \qquad (2)$$

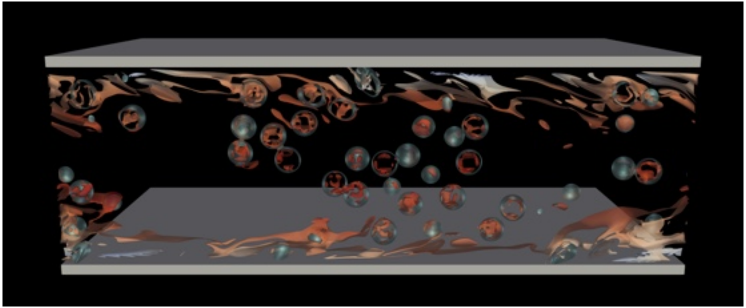


[2] Unverdi & Tryggvason 1992 *Journal of Computational Physics* 100, 25–37.

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

Setup: pressure driven channel flow

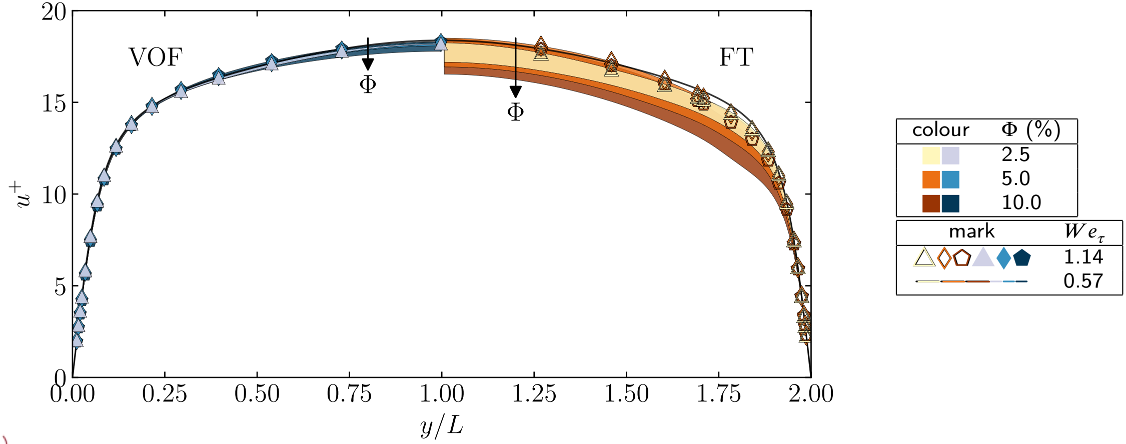
Channel dimensions	$6L \times 2L \times 3L$
VOF: uniform grid	$1296 \times 432 \times 648$
FT: non uniform grid	$566 \times 240 \times 288$



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	$We_\tau \equiv \rho_c u_\tau^2 L/\gamma = 0.57,\ 1.14$

Flow profile

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



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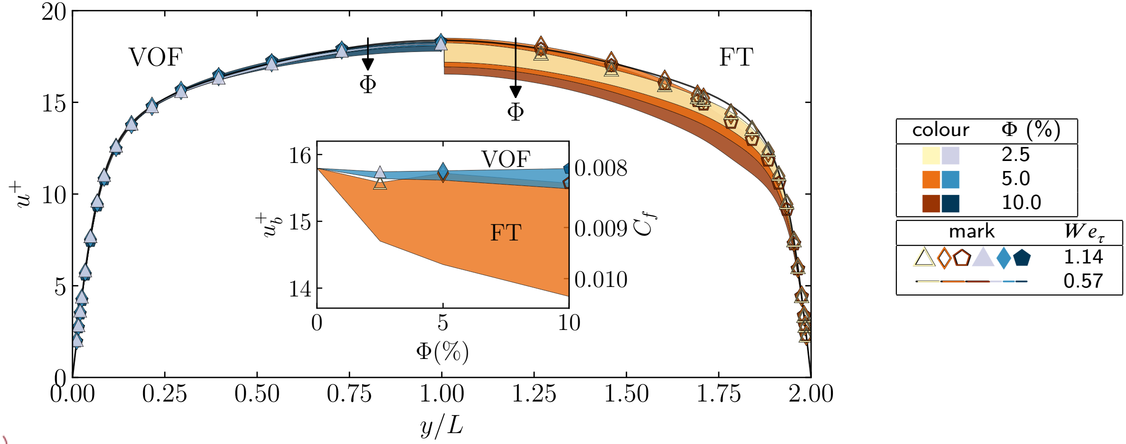
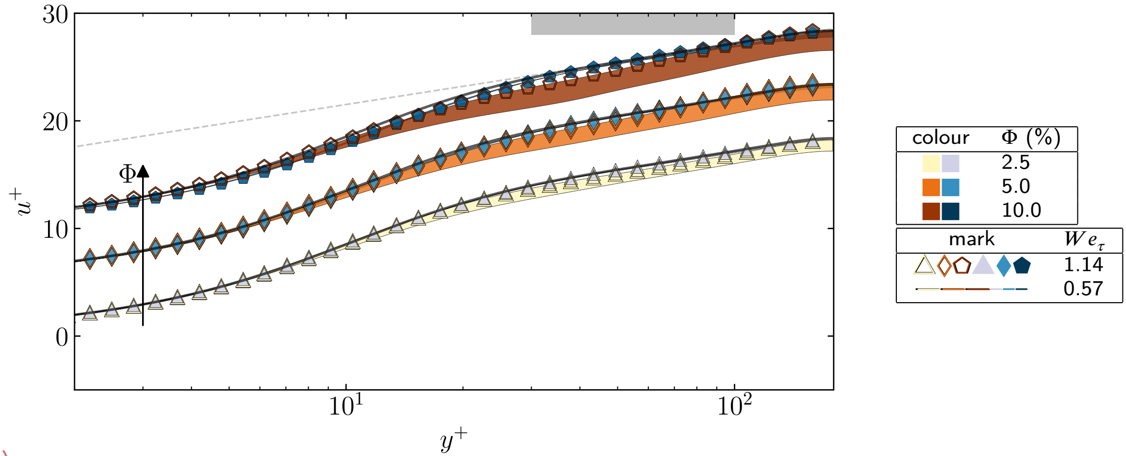


Log-law

The streamwise velocity profiles follow the log-law for a turbulent channel flows, with a **negative shift**[4] $u^+ = 2.5 \log y^+ + 5.5 + \Delta u^+$.



[4] von Kármán, T. 1930. Mechanische Ahnlichkeit und Turbulenz. Math-Phys. Klasse.

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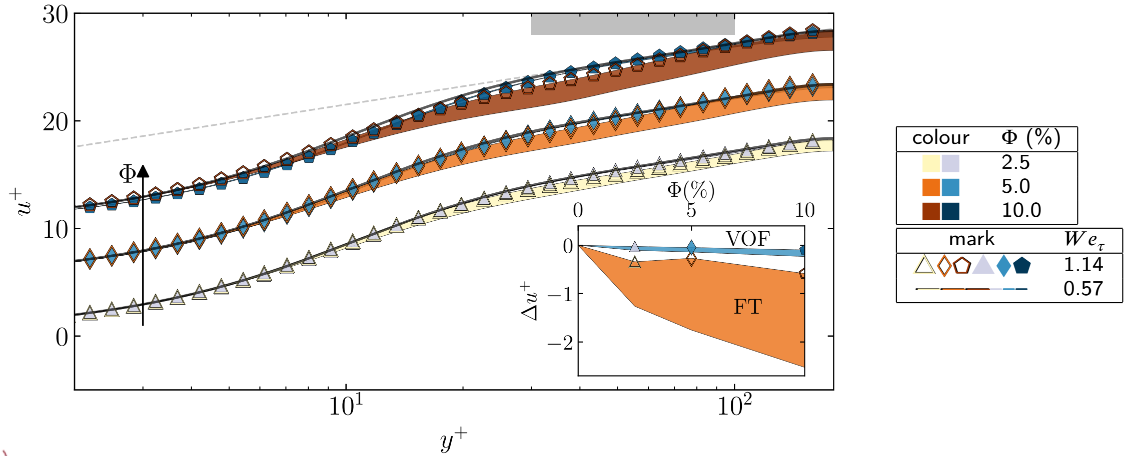

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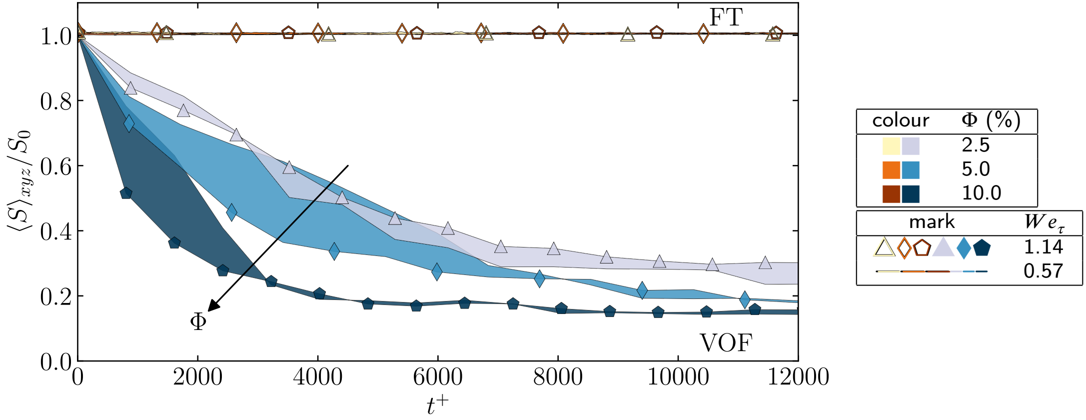
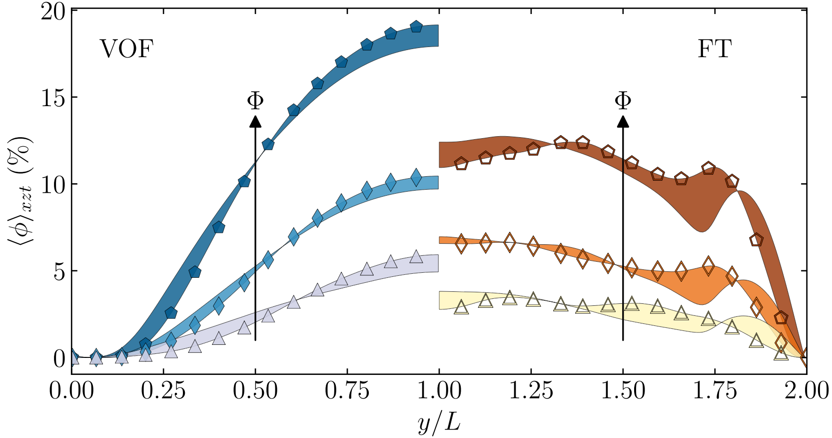
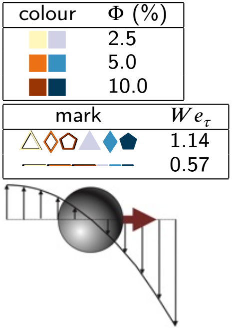
Total area of the bubbles

Coalescence leads to a significant **decrease in surface area**.



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[5].

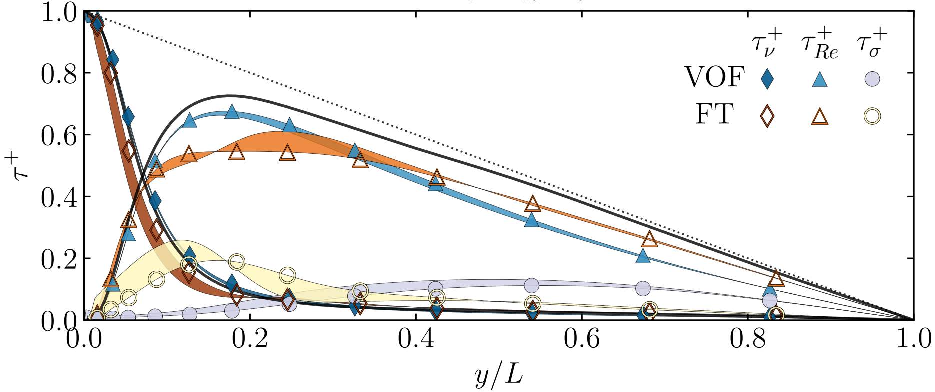
Front tracking bubbles experience a **shear-gradient lift force**, pulling them toward the wall.

[5] 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,

$$1 - y/L = \tau_\nu^+ + \tau_{Re}^+ + \tau_\sigma^+ \tag{3}$$



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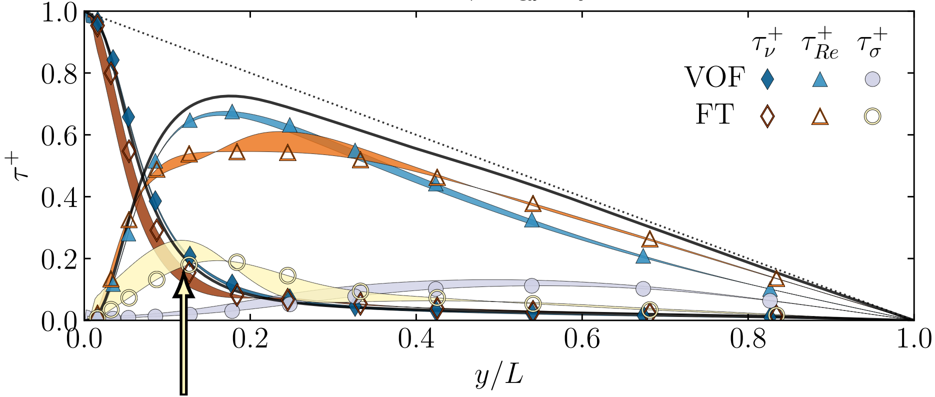
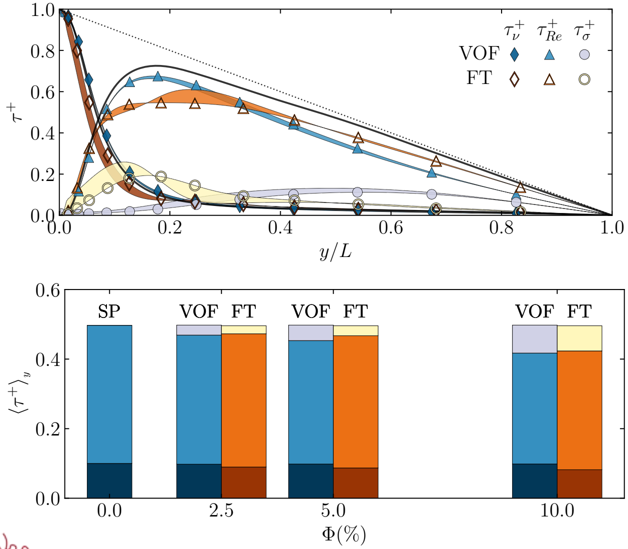


The front tracking **surface tension stress** has a peak near the wall.

Shear stresses

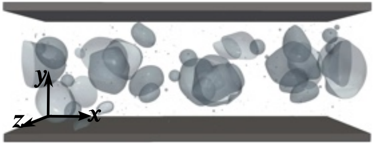


The mean viscous shear stress is reduced in the front tracking simulations.
This stress is proportional to the centreline velocity,

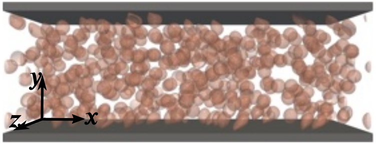
$$\langle \tau_\nu^+ \rangle_y = \frac{1}{L}\int_0^L \frac{du^+}{dy^+} dy = \frac{\delta_\nu}{L} u_{cen}^+. \qquad (4)$$

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

Conclusions & future work



Volume of fluid method



Front tracking method

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.

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.

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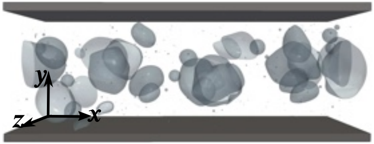

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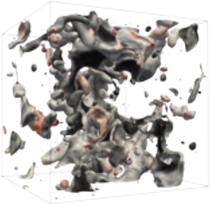
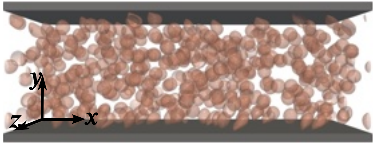


Surfactant model



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4. Future work with **G. Soligo**: modelling the surfactant as a **third fluid phase**

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.