Chair: Physics of Fluids group

# A deeper understanding of bubble drag reduction in Taylor–Couette flow

## Description

The maritime industry is a noticeable contributor to global greenhouse gas emissions and is constantly striving to be more environmentally friendly [1]. An attractive approach, which has been put into real-life application [2], is to introduce bubbles beneath a ship's hull. This method is traditionally examined by modelling the ship's hull with a flat plate. However, the system's behaviour depends on the streamwise distance and the amount of drag reduction tapers off downstream, making it tricky to delineate different effects. To overcome this difficulty, bubble drag reduction has been studied in Taylor–Couette flow [3], which is the flow driven by two concentric independently rotating cylinders (see figure 1(a)). This system is rotationally symmetric and and has been used in multiple studies to study bubble drag reduction. These studies argue that at high Reynolds number, bubble drag reduction in Taylor–Couette flow is caused by bubble deformability [4], [5] and large bubbles are required for drag reduction [6].

Here, we propose a mechanism to explain bubble drag reduction in this system. When the inner cylinder rotates (with the outer cylinder stationary), bubbles are pushed into the boundary layer by the centripetal force as depicted in figure 1(b,c). Van Gils et al. [5] have already shown that the local air volume fraction close to the inner cylinder is higher than the average air volume fraction. The lower absolute viscosity of the bubbles compared to the liquid reduces the local shear stress hence the drag. The goal of this project is to verify/falsify this hypothesis.

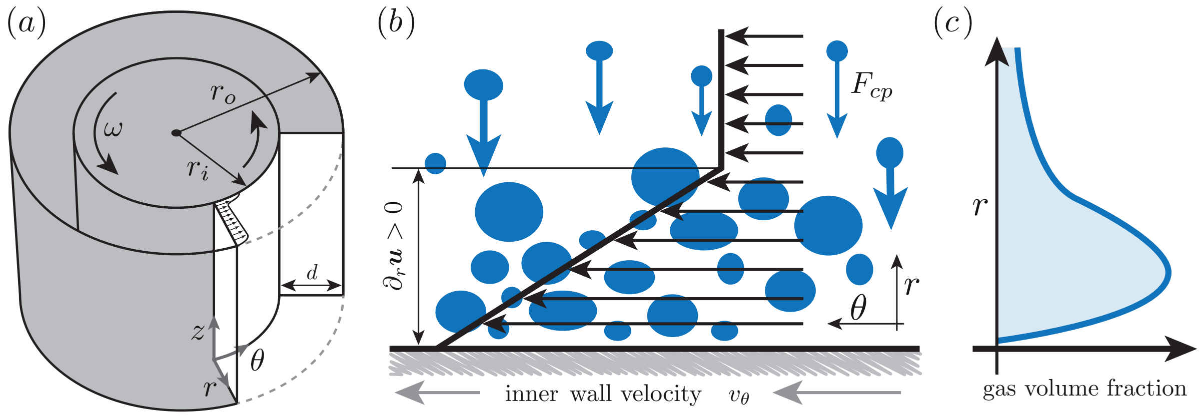


Figure 1: (a) Sketch of the Taylor–Couette flow. (b) Bubbles are pushed towards the inner cylinder into the boundary layer by the centripetal force. (c) A plot of the expected gas volume fraction as a function of radial distance — most of the bubbles are located in the boundary layer near the inner cylinder.

## Assignment

In this project, you will investigate whether the proposed mechanism is supported by experimental observations. To do so, we will measure the local air volume fraction in the boundary layer. Experiments will be performed in the Twente Turbulent Taylor–Couette setup (T3C) [7] which is shown schematically in figure 1a and in figure 2a. The inner and outer cylinder radius are $r_i = 0.2m$ and $r_o = 0.279m$ respectively. The height of the setup is $L = 0.927m$. Rotating the inner cylinder up to 1200rpm results in a highly turbulent flow with a Reynolds number of approximately $Re \approx 2 \times 10^6$. This highly turbulent flow will distribute the bubbles throughout the measurement volume.

As adding bubbles makes the flow opaque, high speed cameras can only capture bubbles close to the outer cylinder. A typical image is shown in figure 2b. One possibility to measure the local air volume fraction in the boundary layer near the inner cylinder is using optical fibres.

Adding salts or surfactants to the flow affects the bubble coalescence and with that the bubble sizes [6]. Different bubble sizes will affect the centripetal forces on the bubbles which might alter the bubble distribution. By measuring the bubble distribution using the optical fibre probes over a wide parameter range, we hope to prove/disprove our hypothesis.

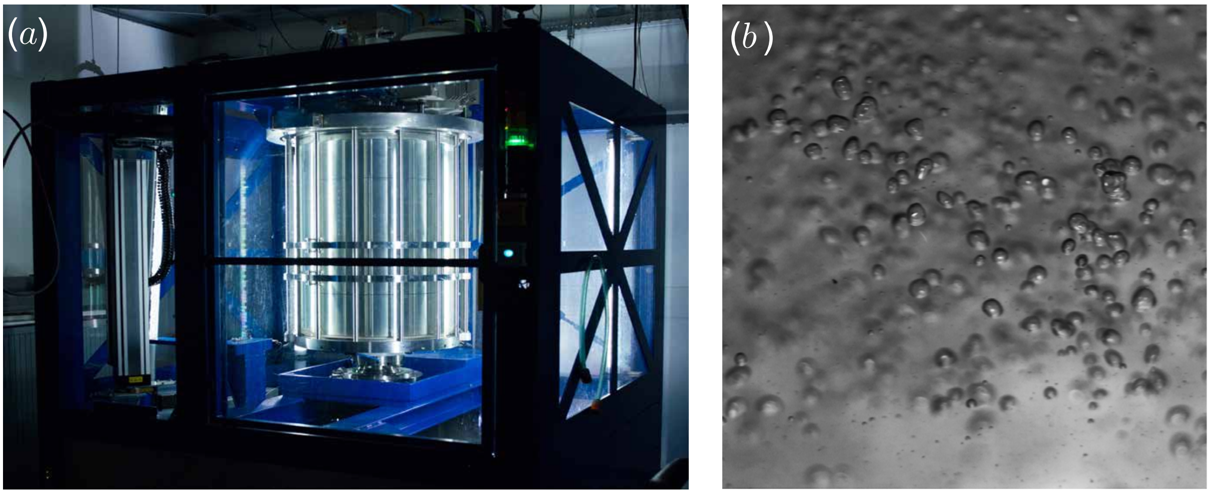


Figure 2: (a) Picture of the Twente Turbulent Taylor–Couette setup. (b) Snapshot of bubbles close to the outer cylinder.

For questions, please feel free to contact Timothy Chan (t.k.t.chan@utwente.nl) and Luuk Blaauw (l.j.blaauw@utwente.nl).

| Supervision | E-mail | Tel. | Office | Room |
|---|---|---|---|---|
| Timothy Chan | t.k.t.chan@utwente.nl | 053 489 4069 | Meander 247 | Meander 247 |
| Luuk Blaauw | l.j.blaauw@utwente.nl | 053 489 1297 | Meander 246a | Meander 246a |
| Dominik Krug | d.j.krug@utwente.nl | 053 489 1590 | Meander 251 | Meander 251 |
| Sander Huisman | s.g.huisman@utwente.nl | 053 489 2487 | Meander 264 | Meander 264 |

# References

[1] European Commission, *Reducing emissions from the shipping sector*, accessed on 9 Dec, 2021. [Online]. Available: https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en.

[2] M. Giernalczyk and P. Kaminski, "Assessment of the propulsion system operation of the ships equipped with the air lubrication system," *Sensors*, vol. 21, no. 4, p. 1357, 2021.

[3] Y. Murai, "Frictional drag reduction by bubble injection," *Experiments in Fluids*, vol. 55, p. 1773, 2014.

[4] T. H. van den Berg, S. Luther, D. P. Lathrop, and D. Lohse, "Drag reduction in bubbly Taylor-Couette turbulence," *Physical Review Letters*, vol. 94, no. 4, p. 044 501, 2005.

[5] D. P. M. van Gils, D. Narezo Guzman, C. Sun, and D. Lohse, "The importance of bubble deformability for strong drag reduction in bubbly turbulent Taylor–Couette flow," *Journal of Fluid Mechanics*, vol. 722, pp. 317–347, 2013.

[6] R. A. Verschoof, R. C. A. van der Veen, C. Sun, and D. Lohse, "Bubble drag reduction requires large bubbles," *Physical Review Letters*, vol. 117, no. 10, p. 104 502, 2016.

[7] D. P. M. van Gils, G.-W. Bruggert, D. P. Lathrop, C. Sun, and D. Lohse, "The Twente turbulent Taylor–Couette (T3C) facility: Strongly turbulent (multiphase) flow between two independently rotating cylinders," *Review of Scientific Instruments*, vol. 82, no. 2, 025105, 2011. [Online]. Available: http://scitation.aip.org/content/aip/journal/rsi/82/2/10.1063/1.3548924.