Taylor flow entering a porous medium: experiment and simulation

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Motivation

- Millichannels filled with a porous medium are an innovative concept for heterogeneously catalyzed gas-liquid reactions
- Potential benefits include large contact area and enhanced mass/heat transfer at low pressure drop
- Recent experiments studied the stability and coalescence of Taylor bubbles in confined highly porous media [1,2]
- Here, we focus on the hydrodynamics of Taylor flow as it enters the porous medium which has not been studied so far

Experiment

- Square millichannel (2 mm × 2 mm)
- Vitreous carbon foam, 80 PPI, 96% porosity
- Atmospheric pressure and room temperature
- Gas-liquid Taylor flow ($Q_G = 2$, $Q_L = 8$ cm³/min)

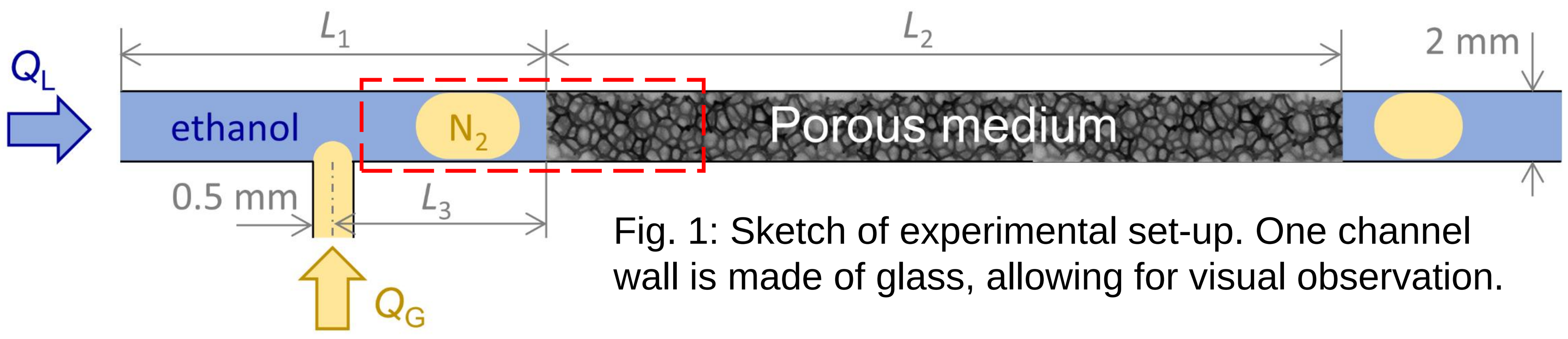

Fig. 1: Sketch of experimental set-up. One channel wall is made of glass, allowing for visual observation.

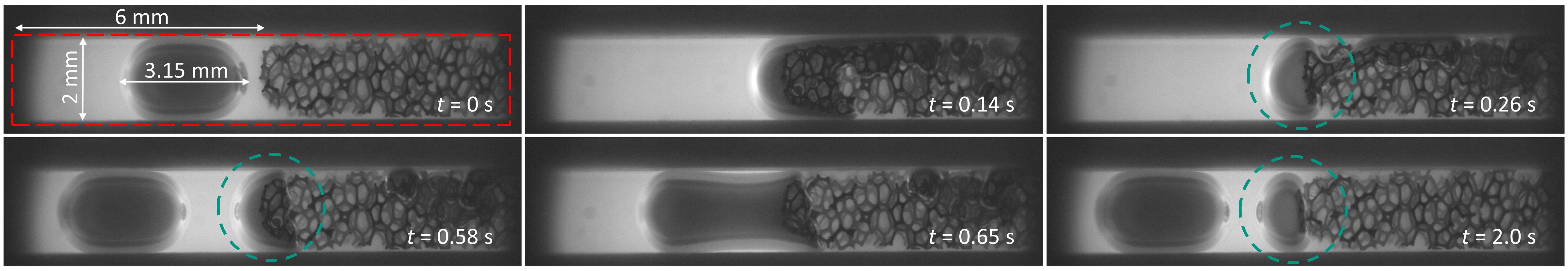

Fig. 2: Visualizations of the penetration of individual Taylor bubbles into the porous medium at six instants in time. The top row shows the same bubble.

- Periodic **bubble capture in front of the foam** (t = 0.58 s, t = 2.0 s) by gas pinch-off from Taylor bubble tail (t = 0.26 s)

Numerical simulation

- Phase-field method with solution of Cahn-Hilliard-Navier-Stokes equations in OpenFOAM [3]
- Axially reduced geometry with foam obtained via X-ray tomography and 3D image reconstruction

	Experiment	Simulation
L_1 [mm]	40	14
L_2 [mm]	160	8
L_3 [mm]	10	9.5

- Steady state simulation with liquid entering at both inlets to determine initial velocity field for G/L run
- Transient simulation where phase at bottom inlet is switched from liquid to gas (contact angle 30°)

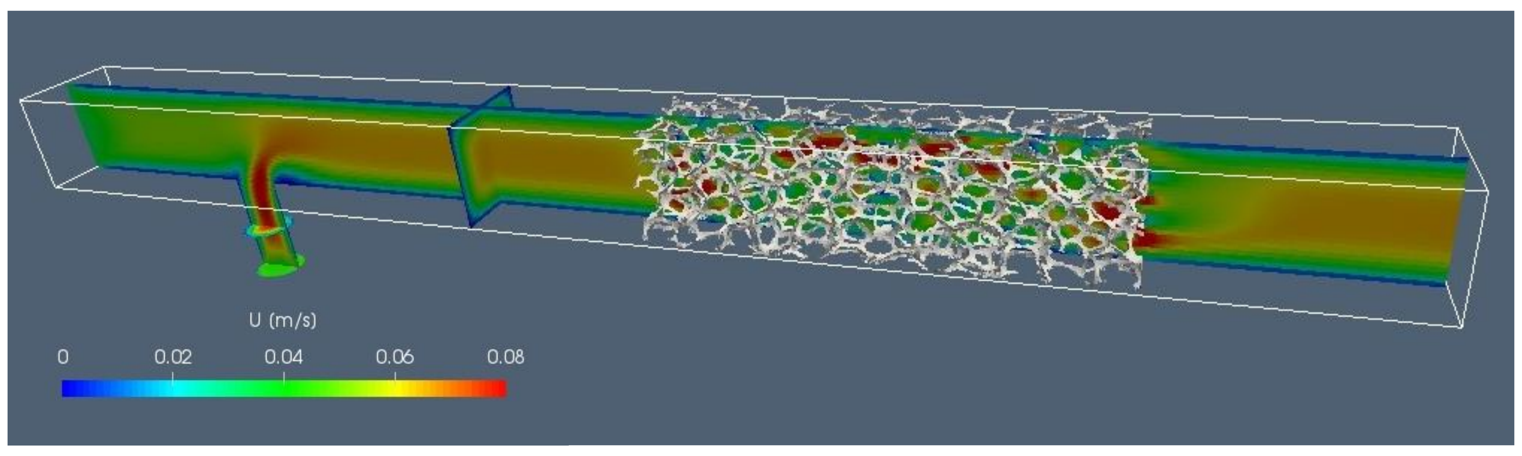

Fig. 3: Steady velocity field of single phase flow simulation with liquid entering at both inlets.

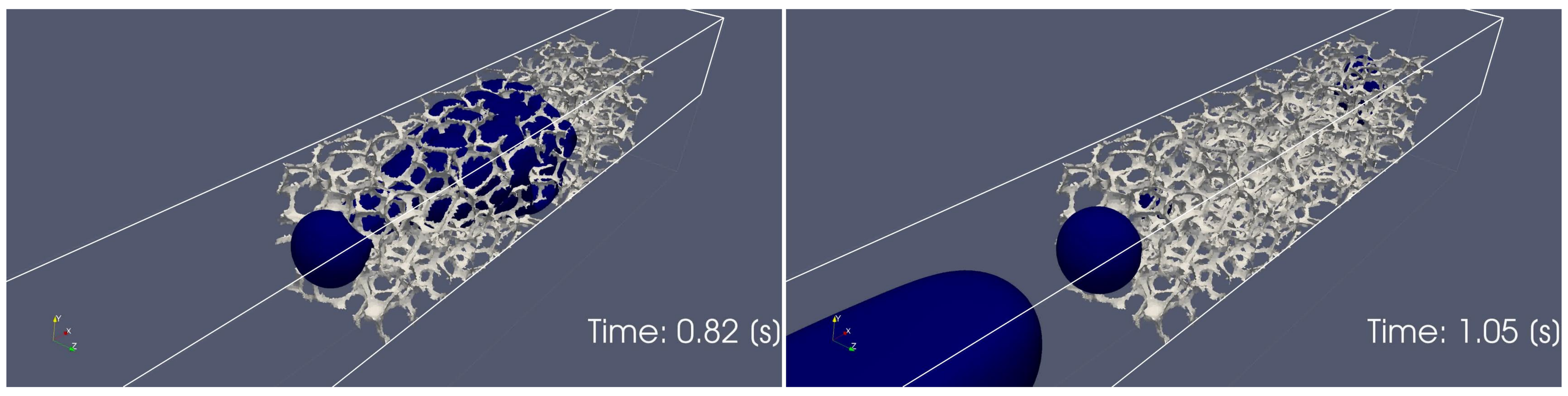

Fig. 4: Pinch-off of first Taylor bubble (left) and approach of the 2nd Taylor bubble (right). Similar to the experiment, gas is captured in front of the foam. A similar simulation with surface tension reduced by 50% shows penetration of the entire Taylor bubble instead.

Conclusions

- Taylor bubbles may not penetrate completely into a porous medium due to gas pinch-off at the bubble tail
- Gas capture in front of the porous medium occurs when viscous forces are too small to enforce bubble fragmentation
- Simulations with quite coarse grid reproduce the experiments, demonstrating the potential for more detailed studies

[1] M. Serres et al., Int. J. Multiphase Flow **85** (2016) 157-163
[2] M. Serres et al., Int. J. Multiphase Flow **87** (2018) 134-141
[3] X. Cai et al., Chem. Eng. Technol. **38** (2015) 1985-1992

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