オープンCAE勉強会（気泡塔計算）

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Jet/plume flow

- S. A. Socolofsky, A. Leos-Urbel, E. E. Adams, “Draft Final Report: exploratory experiments with droplet plumes in a cross-flow”, Final Report: Experimental Study of Multi-phase Plumes with Application to Deep Ocean Oil Spills. U. S. Department of the Interior Mineral Management Service Contract No. 1435-01-98-CT-30964.

Socolofsky et al. (1999)

- Gas and oil plumes in a cross-flow

Property	Value
Oil flow rate [ml/min]	250, 600, 1000
Air flow rate [ml/min]	250, 600, 1000, 2500
Oil density [g/cc]	0.87
Cross-flow speed [m/s]	0, 2, 5, 10

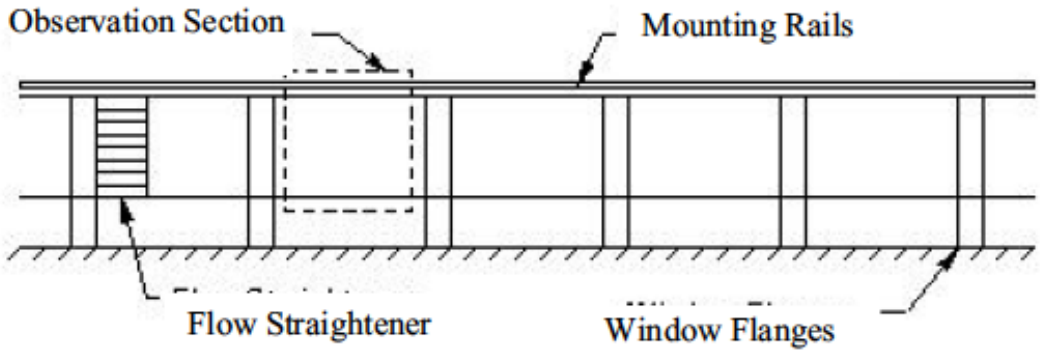


Figure 1: The experimental flume at Parsons Laboratory, MIT. Distance between successive flanges is 1.5 m.

Chen & Yapa (2004)

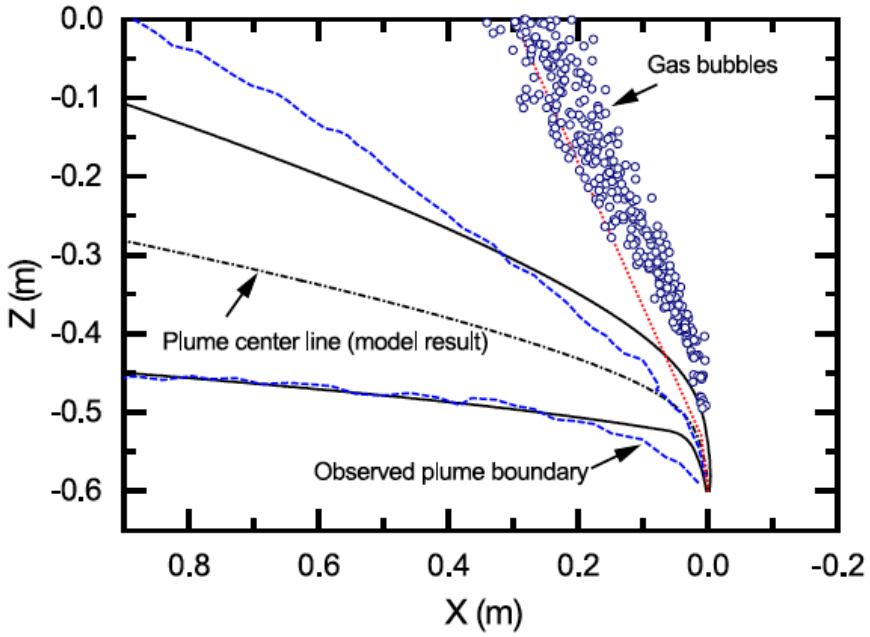


Fig. 2. Multi-phase plume in cross-flow for case S1: numerical simulation-present model; experimental data from Socolofsky et al. (1999).

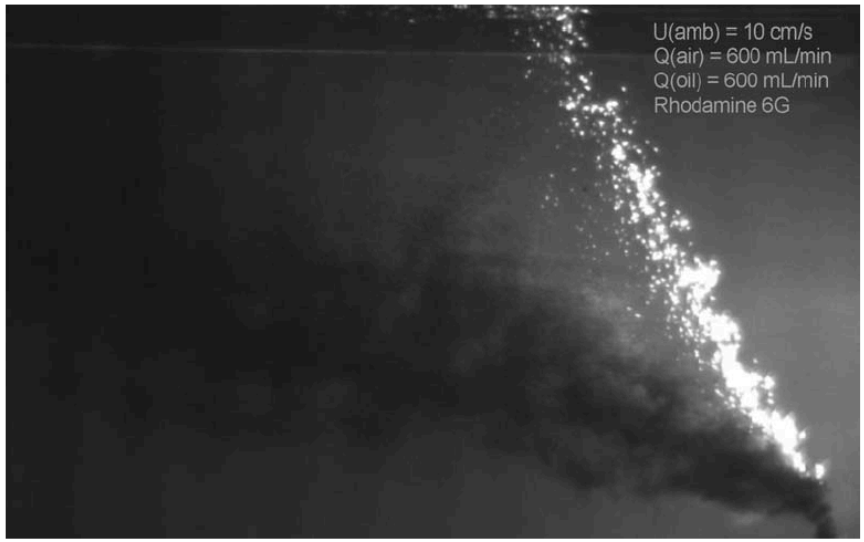


Fig. 3. Video image for case S1 (experiment no. C15, Socolofsky et al., 1999).

Multiphase flow simulation in OpenFOAM

- Governing equations used in *bubbleFoam* solver
  - Continuity equations for each phase φ

$$\frac{\partial}{\partial t}\left(\alpha_\varphi \rho_\varphi\right)+\nabla\cdot\left(\alpha_\varphi \rho_\varphi \mathbf{U}_\varphi\right)=0$$

  - Phase momentum equation

$$\frac{\partial}{\partial t}\left(\alpha_\varphi \rho_\varphi \mathbf{U}_\varphi\right)+\nabla\cdot\left(\alpha_\varphi \rho_\varphi \mathbf{U}_\varphi \mathbf{U}_\varphi\right)+\nabla\cdot\alpha_\varphi \tau_\varphi+\nabla\cdot\left(\alpha_\varphi \mathbf{R}_\varphi\right)=-\alpha_\varphi \nabla p+\alpha_\varphi \rho_\varphi \mathbf{g}+\mathbf{M}_\varphi$$

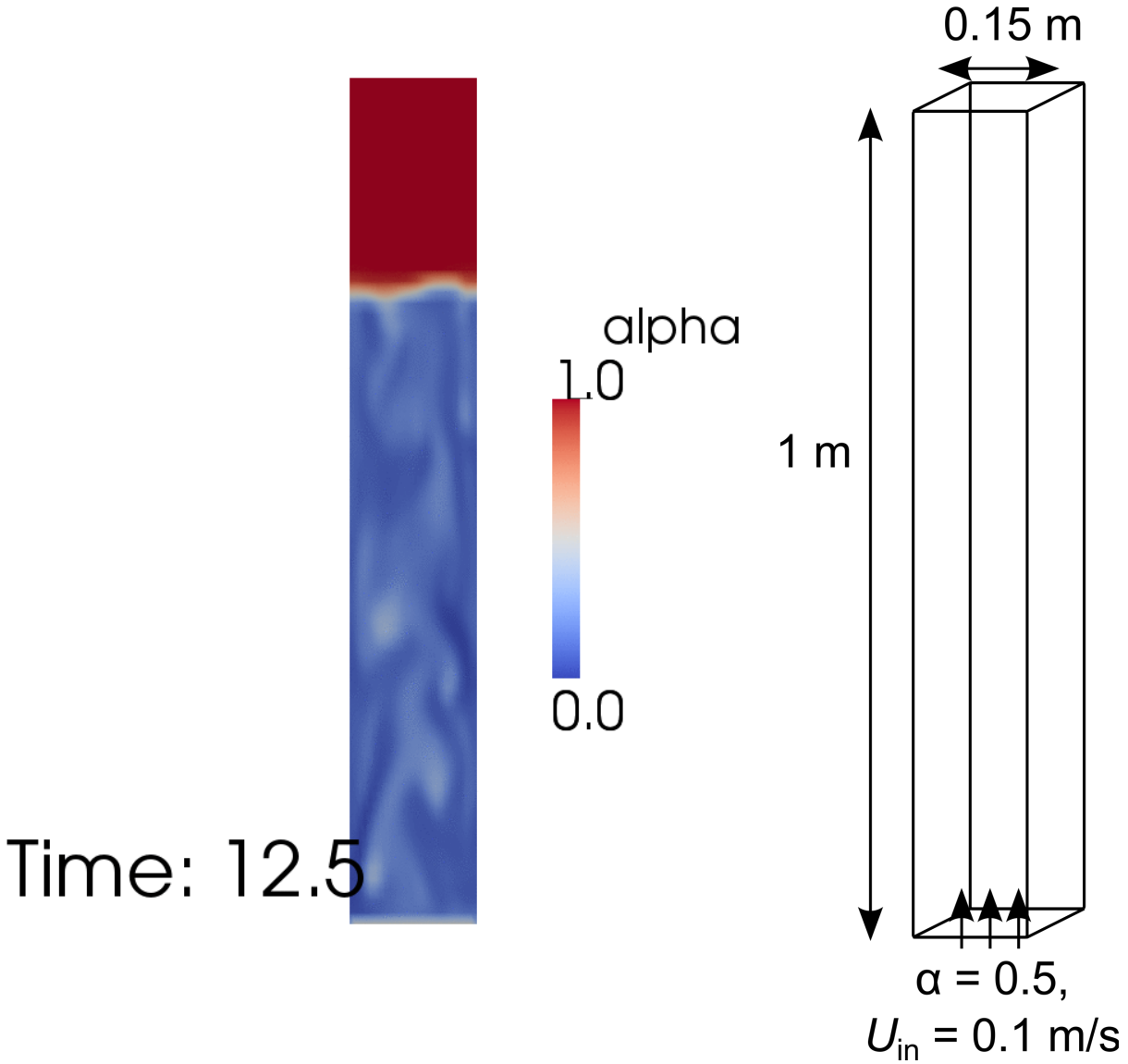
Laminar stress tensor

$$\tau_\varphi=-\rho_\varphi \nu_\varphi\left[\nabla\mathbf{U}_\varphi+\nabla^{\mathrm{T}}\mathbf{U}_\varphi\right]+\frac{2}{3}\rho_\varphi \nu_\varphi\left(\nabla\cdot\mathbf{U}_\varphi\right)\mathbf{I}$$

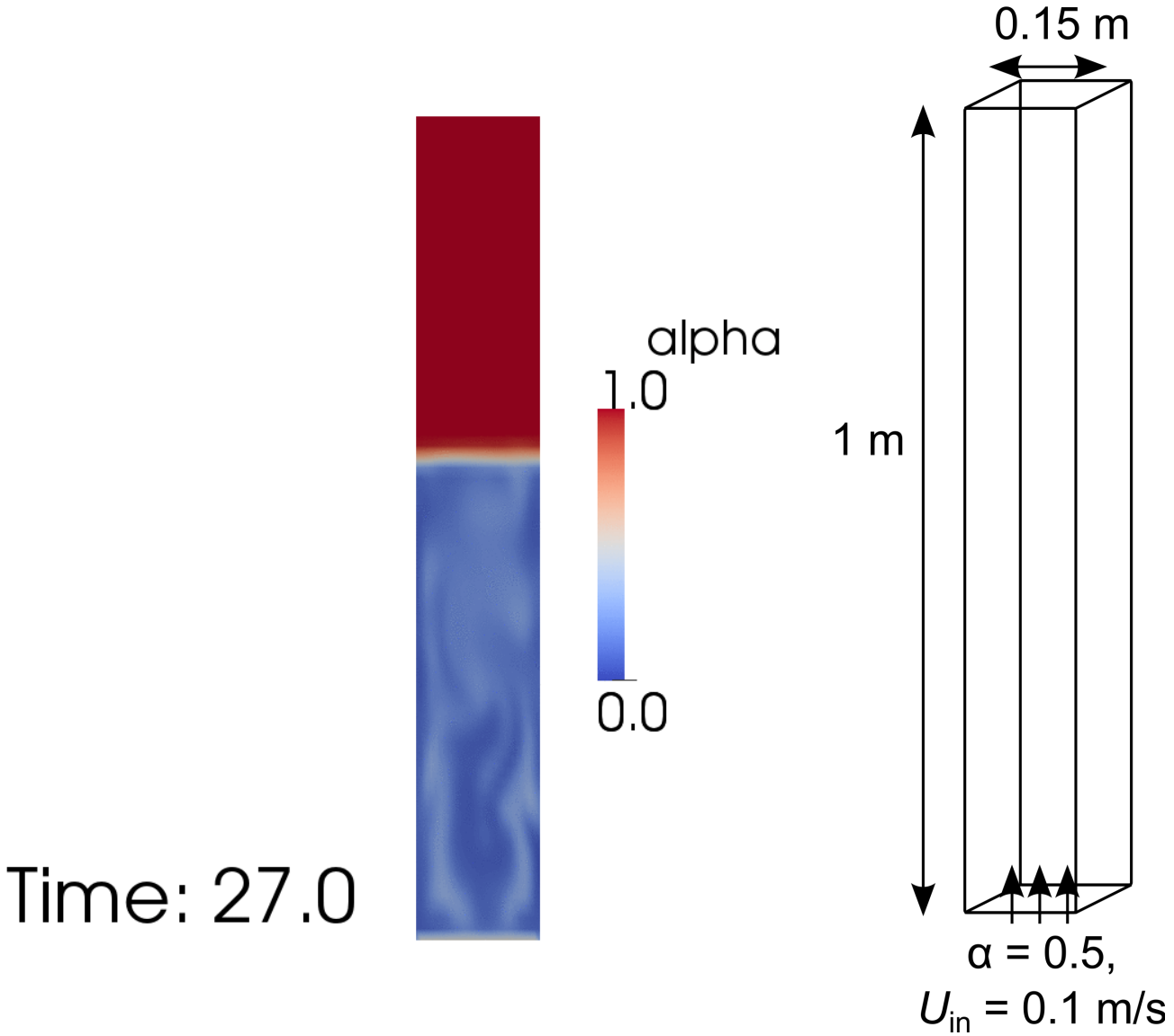
Reynolds stress tensor

$$\mathbf{R}_\varphi=-\rho_\varphi \nu_{\varphi,t}\left[\nabla\mathbf{U}_\varphi+\nabla^{\mathrm{T}}\mathbf{U}_\varphi\right]+\frac{2}{3}\rho_\varphi \nu_{\varphi,t}\left(\nabla\cdot\mathbf{U}_\varphi\right)\mathbf{I}+\frac{2}{3}\rho_\varphi \kappa_\varphi \mathbf{I}$$

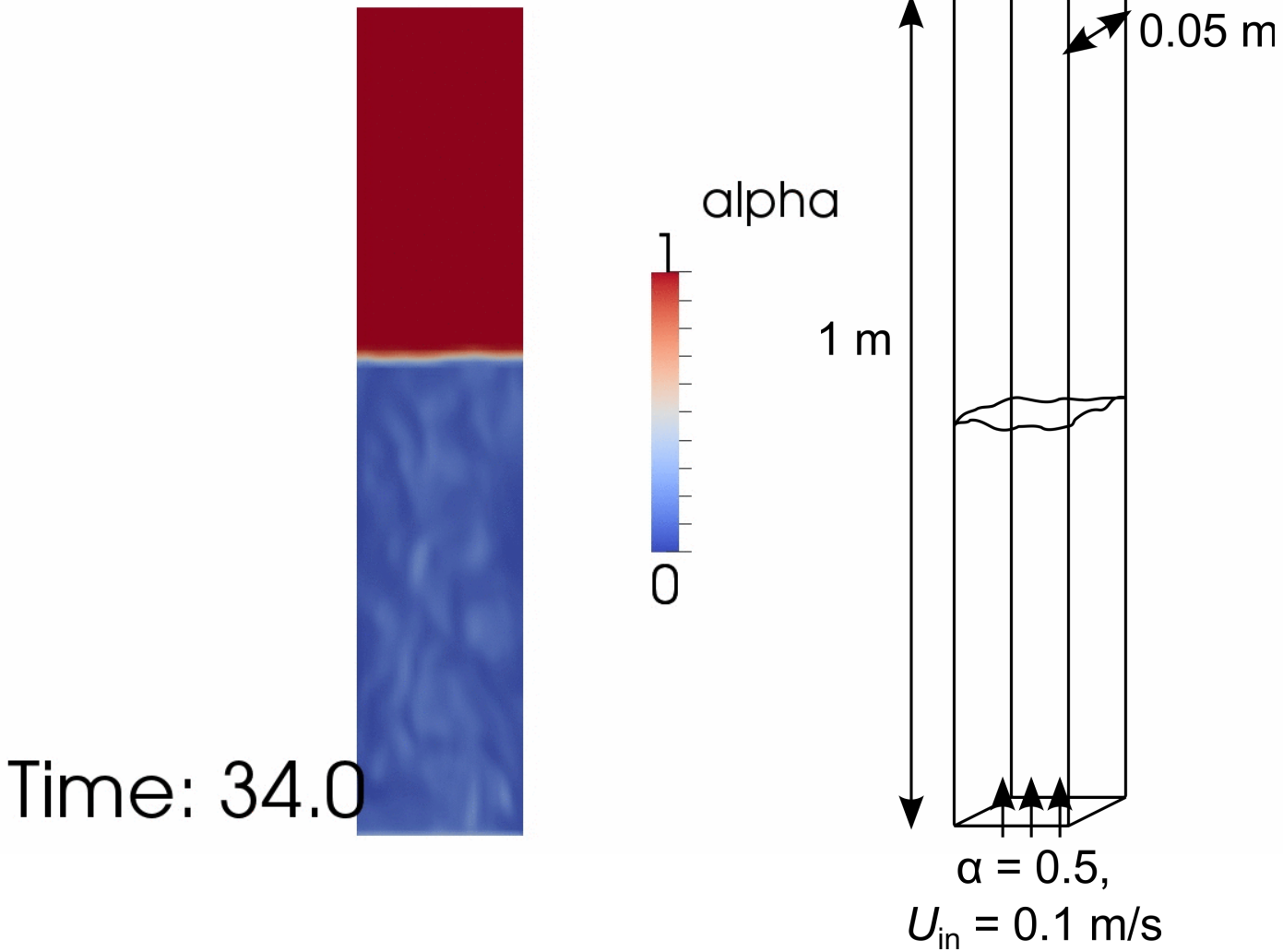
Sample simulation: 2D bubble column (tutorial)



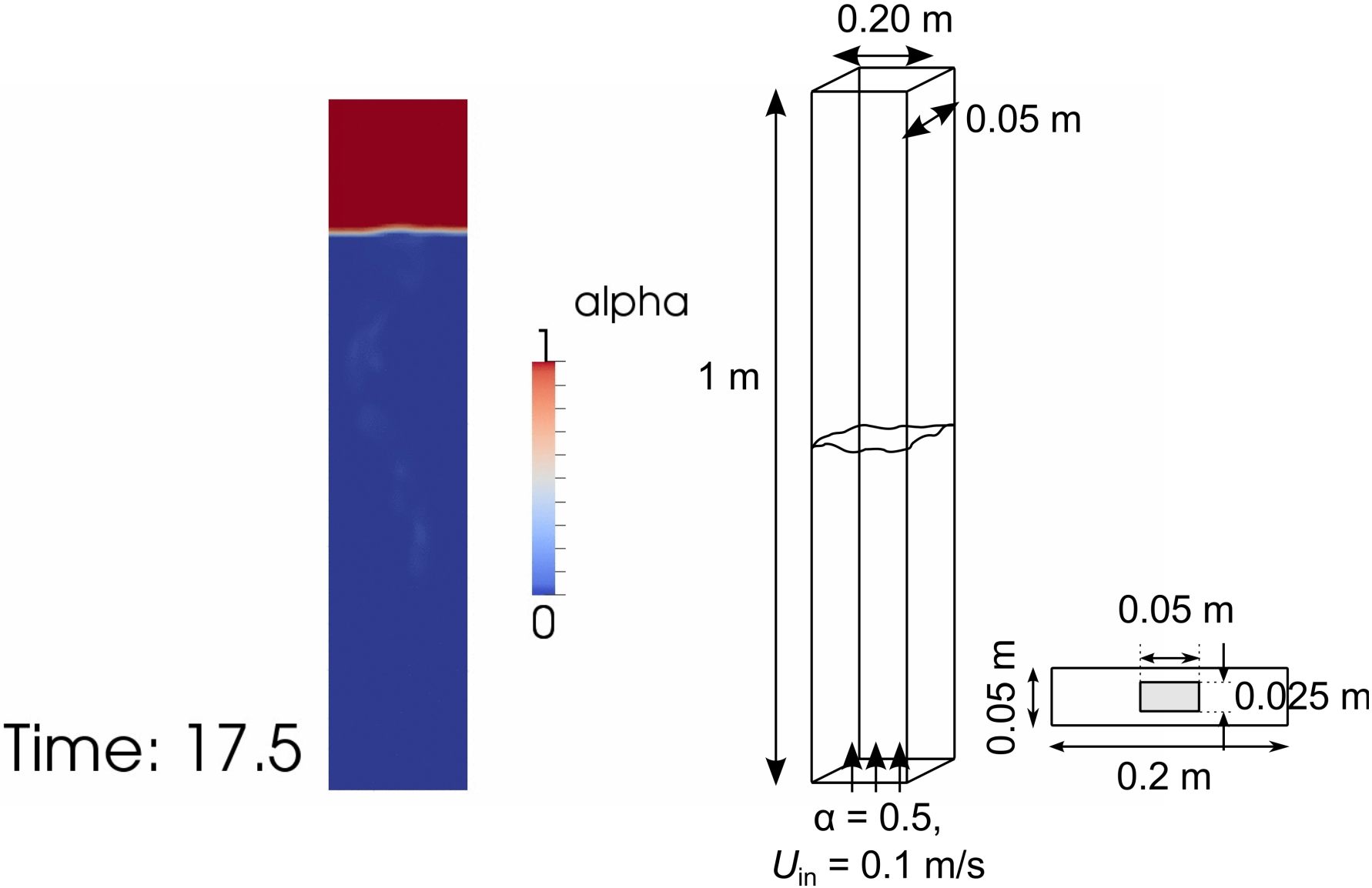
Sample simulation: 2D bubble column (I.C.: U = 0)



Sample simulation: 3D bubble column (I.C.: U = 0)



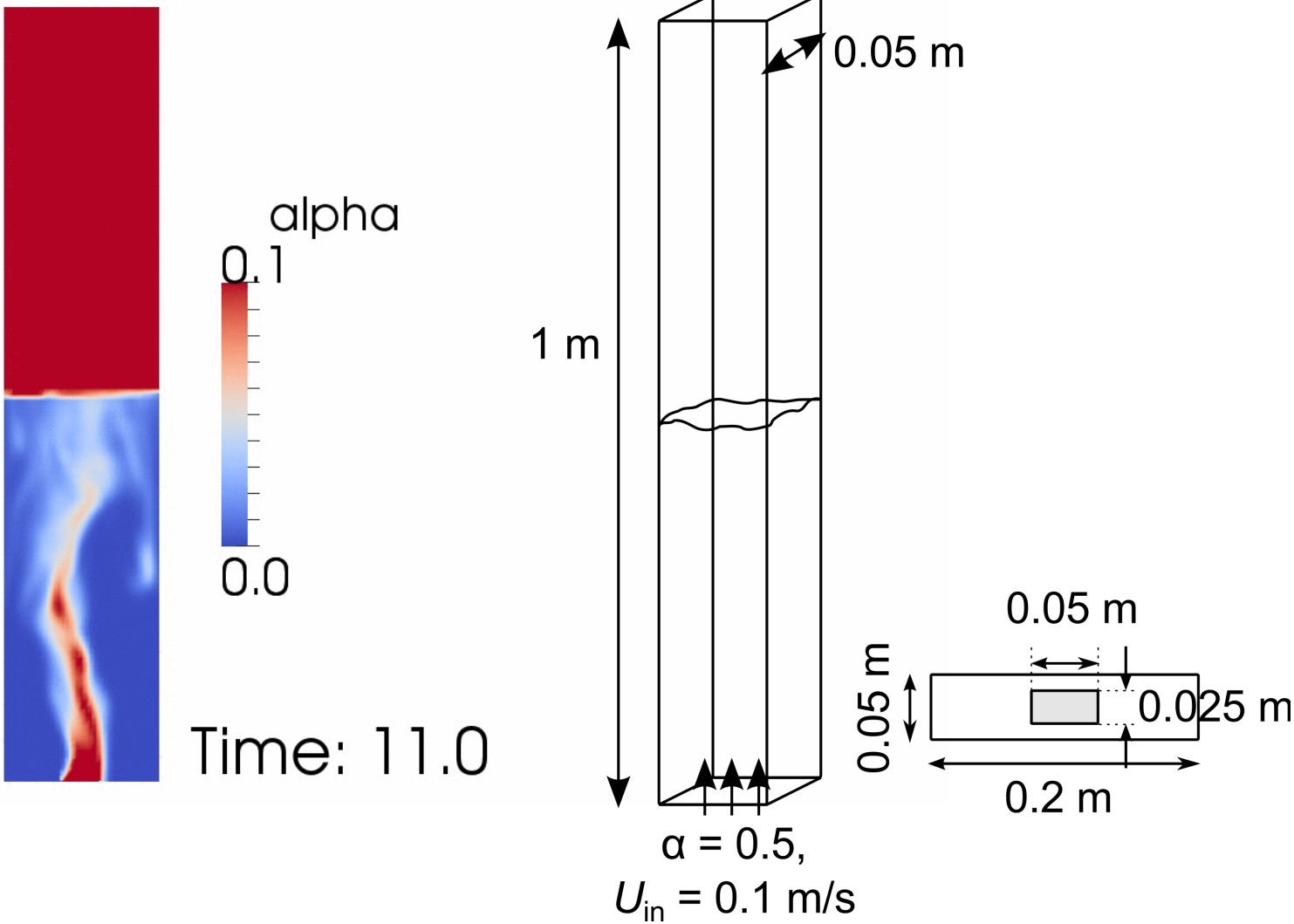
Sample simulation: 3D bubble column (wrong B.C., I.C.: U = 0)



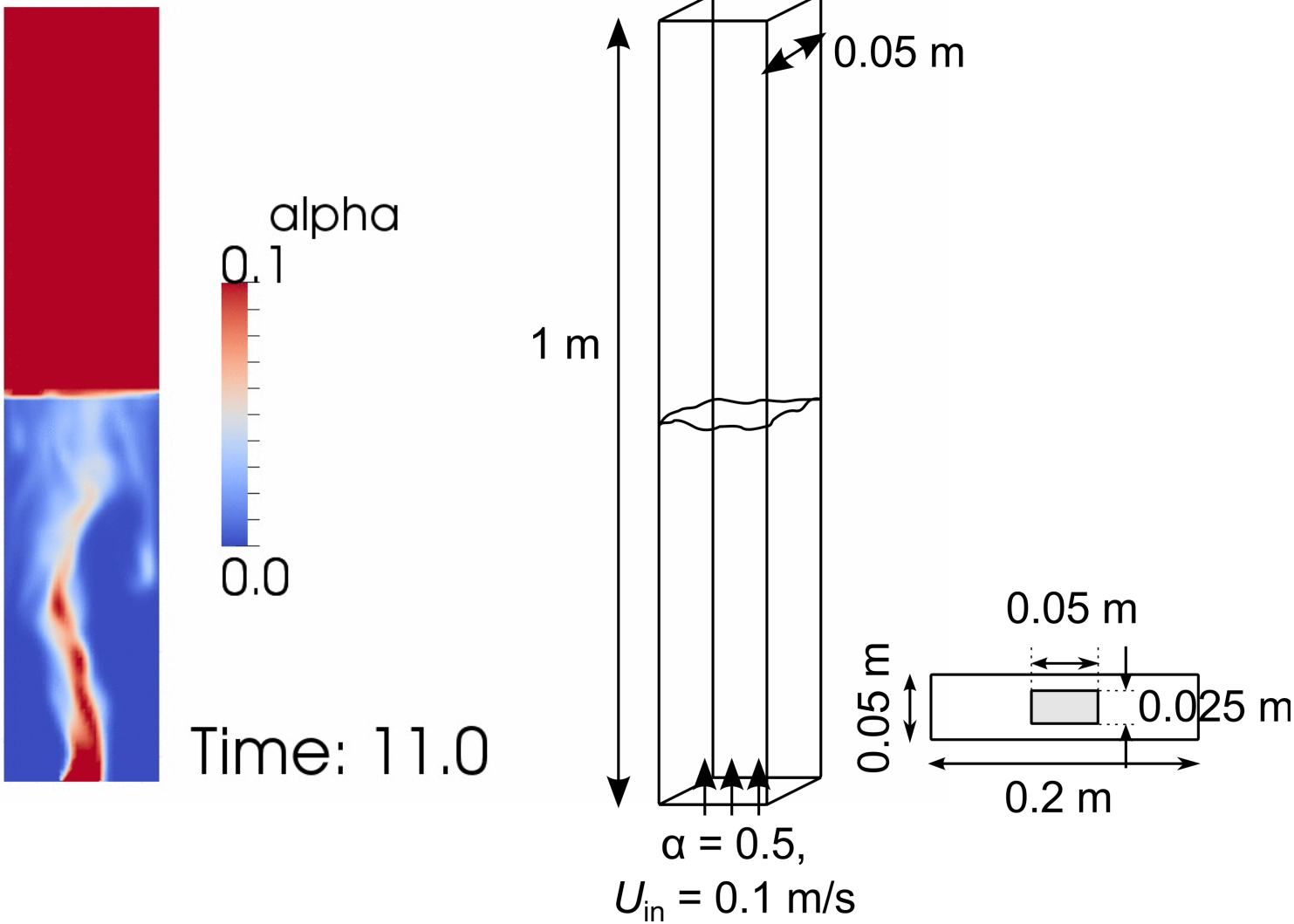
Improvements

- B.C. for pressure at inlet
  - "zeroGradient" to "fixedFluxPressure"
  - When "fixedFluxPressure" is used, the pressure gradient is adjusted by the predicted flux.
  - That is, the mass balance is conserved with the pressure gradient adjustment.

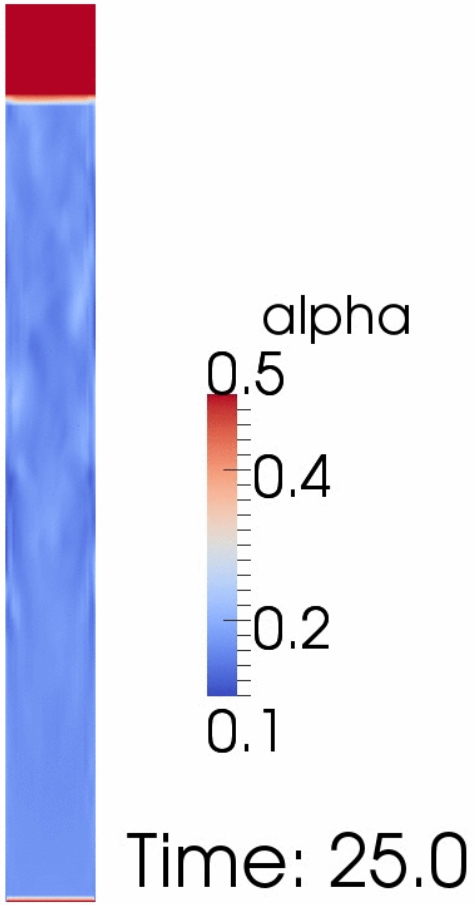
3D bubble column (correct b.c.)
(I.C.: U = 0)

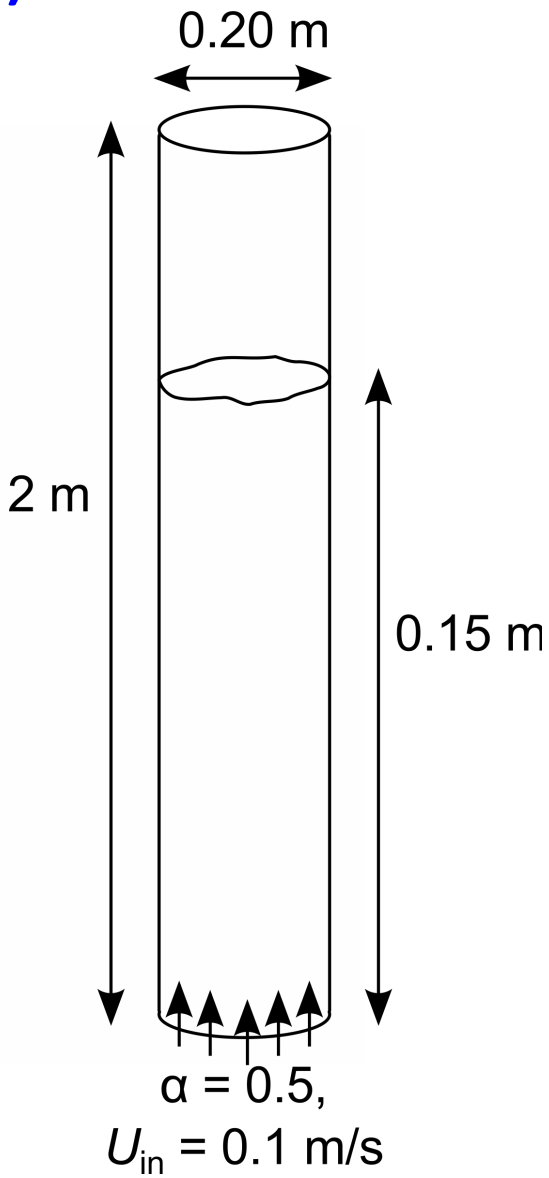


3D bubble column (correct b.c.)
(I.C.: U = 0)



Cylinder bubble column (I.C.: U = 0)





Summary

- Proper b.c. was found, and bubble column simulations were successfully conducted.

- Future work
  - Validation with experimental data
  - Extension to the towing tank test case by Socolofsky et al.
  - Estimation of required grid resolution