Exploring the flow of two immiscible fluids in a square mini-channel by direct numerical simulation

B.E. Ghidersa, M. Wörner, D.G. Cacuci
Institute for Reactor Safety

7th International Conference on Microreaction Technology
Lausanne, September 7-10, 2003

Motivation

Mini-channels: D_h~1 mm

- Cooling of fusion blankets, compact heat exchangers, chemical processing
- Rectangular channels
  - → 3D effects
- Two-phase flows:
  - → strong surface tension effects
  - → "small" deformable bubbles

Experiments: non-intrusive methods

- Global parameters: mass flow rate, pressure drop, temperature or concentration
- Local characteristics (2D): image processing
  - bubble shape and velocity
  - velocity profiles in the liquid (PIV)

Objectives:

- Numerical simulation of the local flow characteristics
- 3D flow structure both in the liquid and inside the bubble

Subject:

- Incompressible periodic gas-liquid flow: bubble-train flow

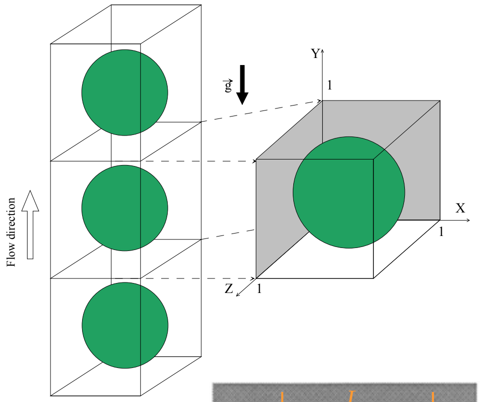
TURBIT-VoF

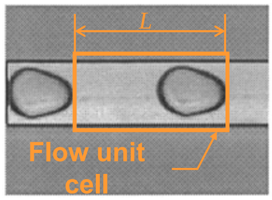
- In-house computer code
- Applicability:
  - incompressible single and two-phase flows
  - plane and rectangular channels
- Features
  - dimensionless Navier-Stokes equations
  - volume tracking method: Volume-of-Fluid (VoF)
    $\Rightarrow$ mass conservation in long time simulations
  - interface is locally approximated with a plane
  - heat transport equation

Bubble-train flow in small channels

Numerical setup

- Square channel ($L \times L$)
- Rigid lateral walls
- Periodic b.c. in flow-direction
- Flow unit cell: L
  - $\Rightarrow$ computational domain: $1 \times 1 \times 1$
- Initial bubble diameter: $D_B = 0.858 \times L$
  - $\Rightarrow$ void fraction α = 33%
- Mesh: 64x64x64
- Constant pressure drop in flow direction
  - $\Rightarrow$ determine the liquid/gas flow rates





Triplett et al., Int J Multiphase Flow., 25, pp 377, 1999

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Comparison with experiments

T.C. Thulasidas *et al* (1995)*

- vertical channel (L = 2 mm)
- silicone oil and air

	$\rho_{liquid} / \rho_{gas}$	ν_{liquid} / ν_{gas}
Case A	813.2	3.19
Case B	775.8	0.32

- Measurements for:
  - ➢ bubble diameter : D_B,
  - ➢ bubble velocity : U_b,
  - ➢ relative bubble velocity : $W=(U_b-v_{ls})/U_b$ (v_{ls} : liquid slug velocity)

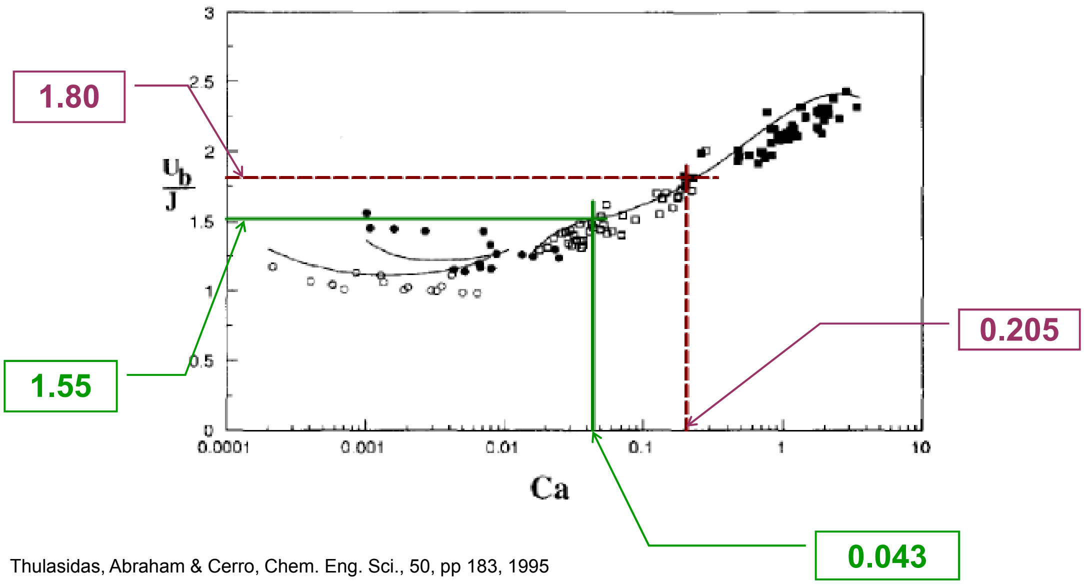
*Thulasidas, Abraham & Cerro, Chem. Eng. Sci., 50, pp 183, 1995

Simulation parameters

	ν_l / ν_g	ρ_l / ρ_g	J_l [cm/s]	J_g [cm/s]	Ca	Re	Eö
Case A	3.2	81	2.82	3.72	0.205	1.35	1.06
Case B	0.32	78	6.52	6.87	0.043	75.8	1.35

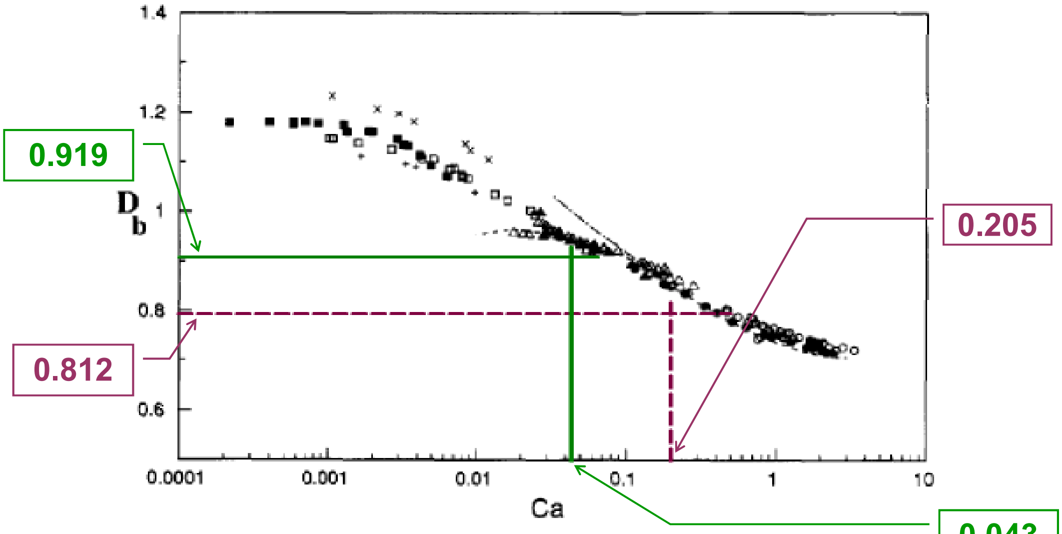
- Capillary number: Ca = $\mu_l U_b / \sigma$
- Reynolds number: Re = $\rho_l U_b D_B / \mu_l$
- Eötvös number: Eö = $(\rho_l - \rho_g) g D_b^2 / \sigma$

Dimensionless bubble velocity (U_b/J)



Thulasidas, Abraham & Cerro, Chem. Eng. Sci., 50, pp 183, 1995

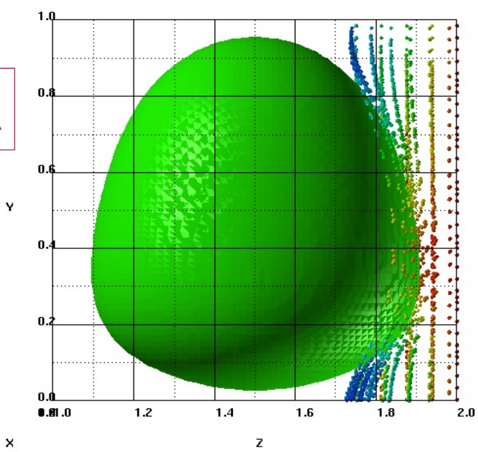
Dimensionless Bubble Diameter (D_B/L)



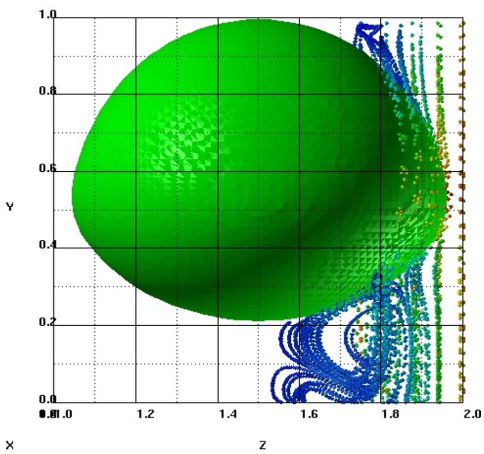
Thulasidas, Abraham & Cerro, Chem. Eng. Sci., 50, pp 183, 1995

Bubble shape and liquid flow structure

A



B

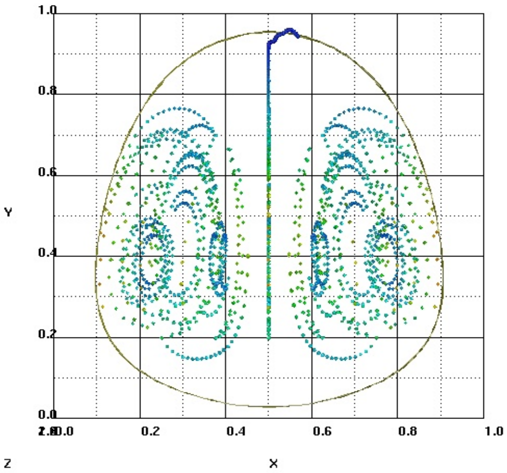


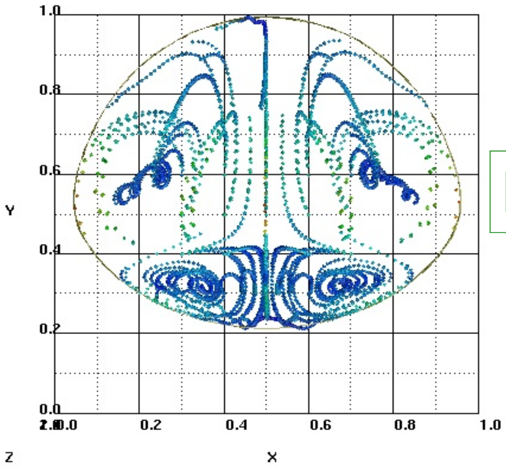
- referential linked to the bubble center of mass

Flow structure inside the bubble

- lateral view -

A





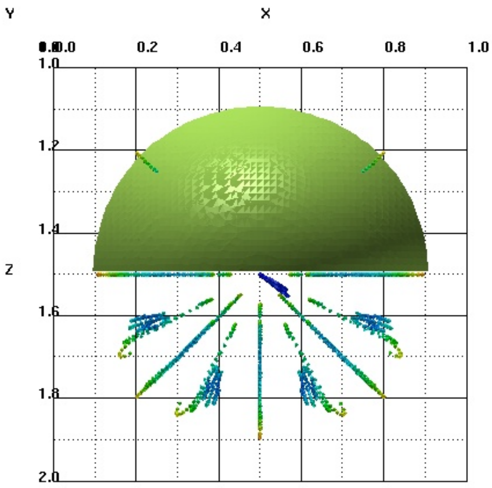
B

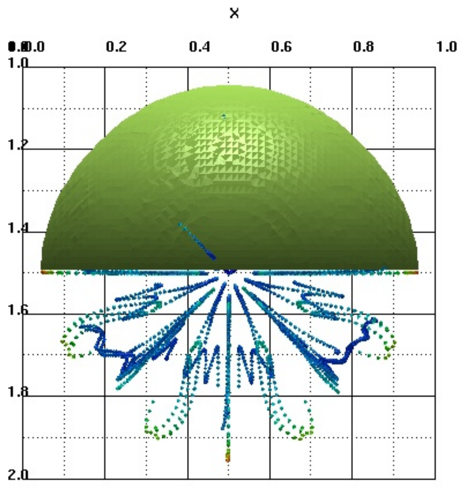
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Flow structure inside the bubble

-top view-

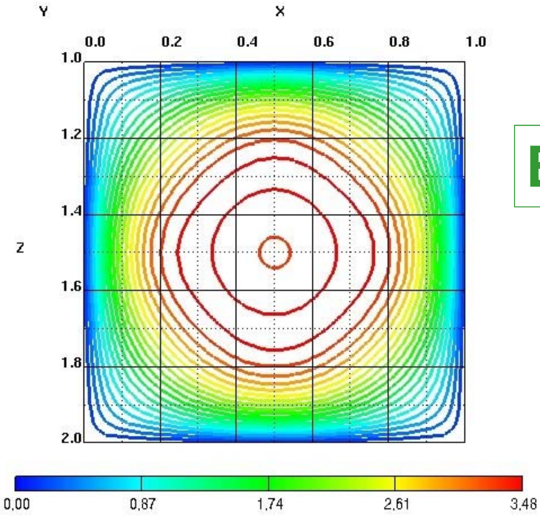
A





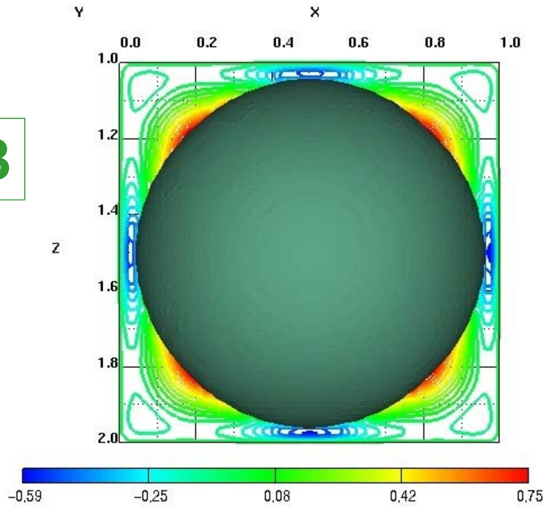
B

Cross-sectional distribution of axial velocity



- slug -

B



- liquid film around the bubble -

Conclusions

- **3D** numerical simulation of a bubble-train flow in a square channel at **low Ca** and **Eö** numbers
- Good agreement with experimental data
- Structure of the flow in the bubble / liquid slug
  - lower Ca:
    - ⇨ intense mixing inside the bubble and in the liquid slug;
    - ⇨ larger bubble diameter : thin liquid layer between the bubble and the wall;
  - higher Ca:
    - ⇨ Flow almost axisymmetric inside the bubble
- Basis for heat/mass transfer characteristics