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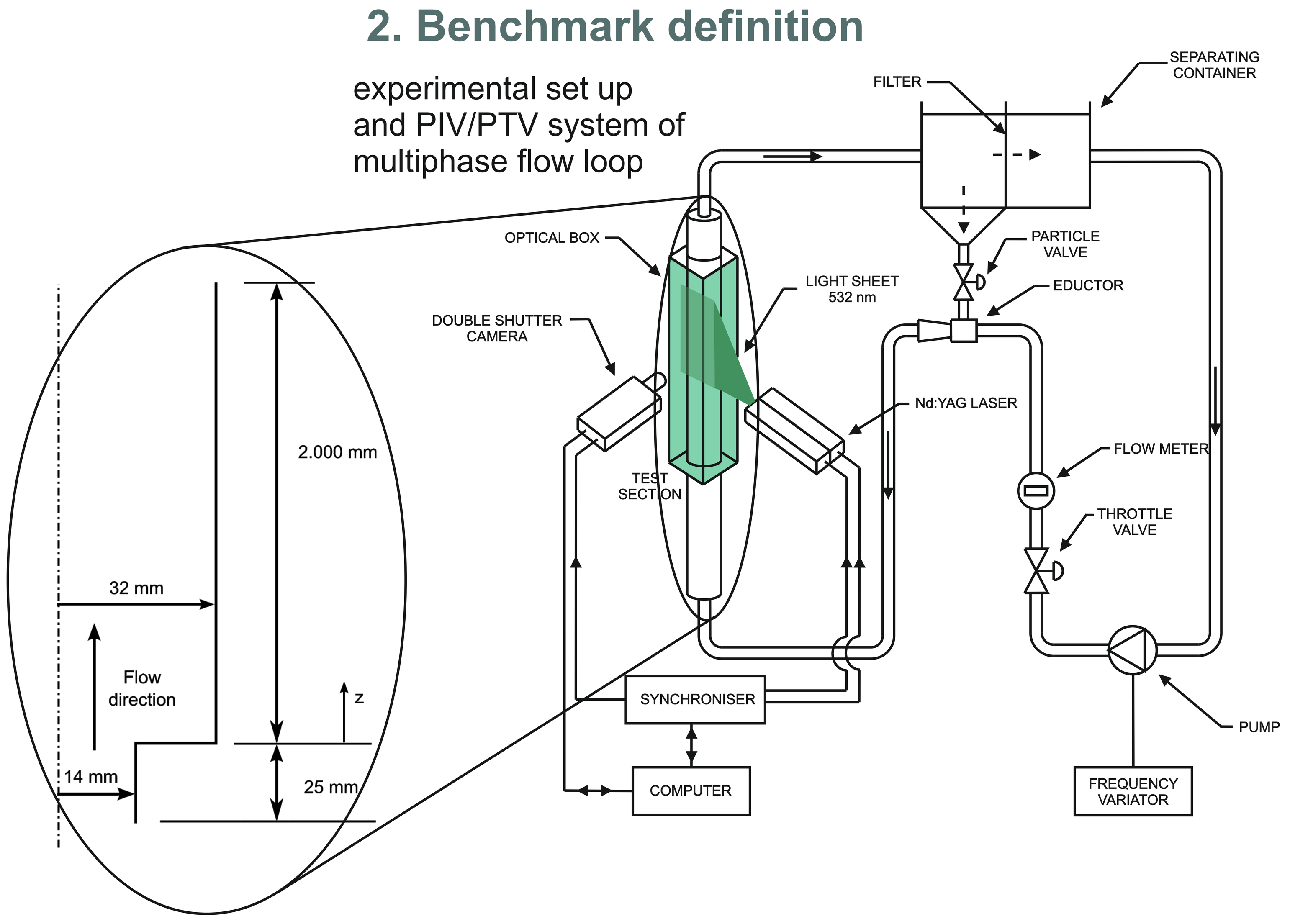
Analysis of bidisperse suspension laminar flows in axisymmetric sudden expansions

1. Introduction

- Drag and lift forces govern the transport of dispersed particles in bounded viscous flow.
- The transverse component of the hydrodynamic force (lift force) plays a crucial role in: (1) radial diffusion and dispersion, (2) wall deposition, and (3) mixing and separation processes [1].
- Physical and numerical experiments are needed to improve the understanding of the rheology and interphase forces in mixtures where multiple species are present.

2. Benchmark definition

experimental set up and PIV/PTV system of multiphase flow loop



Pipe geometry:
- D_c = 64 mm
- d_c = 28 mm
- L_c = 2000 mm

Particles:
- Shape: spherical
- d_p = 2 - 6 mm
- ρ_p = 2230 and 2580 kg/m^3

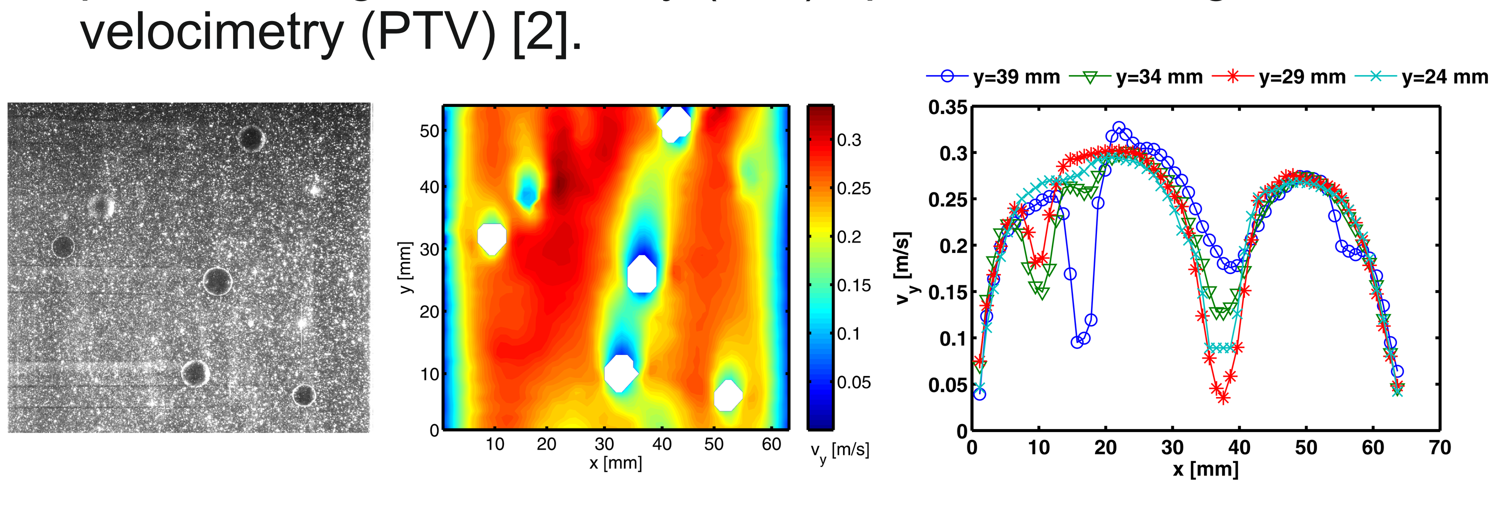
Reynolds numbers:
- $Re_c \sim 300$
- $Re_p = 1 \div 20$

Fluid properties:
- ρ_f = 865 kg/m^3
- μ_f = 72 mPa·s

Suspension properties:
- ϕ (volume load) up to 4%
- Mono- and bidisperse

3. Experimental method

- Measurement of velocity and particle distribution using particle image velocimetry (PIV) / particle tracking velocimetry (PTV) [2].



PIV raw image and reconstructed velocity field

4. Numerical method

- Eulerian-Eulerian Finite Volume Method (FVM) solver for a system of 2 incompressible fluid phases with one phase dispersed (OpenFOAM solver twoPhaseEulerFoam).

$$\frac{\partial}{\partial t}(\rho_i \alpha_i) + \nabla \cdot (\rho_i \alpha_i u_i) = 0$$

$$\frac{\partial}{\partial t}(\rho_i \alpha_i u_i) + \nabla \cdot (\rho_i \alpha_i u_i u_i) = -\alpha_i \nabla p + \rho_i \alpha_i g + \nabla \cdot \tau_i + F$$

α_i : phase volume fraction u_i : phase velocity τ, p : phase stress tensor, pressure
ρ_i : phase density F : phase momentum exchange term

- Implemented lift force model: Saffman-Mei [3]

$$F_{LS} = \frac{\rho_f}{2} \frac{\pi}{4} d_p^2 \, C_{LS} \, d_p \, ((u_f - u_p) \times \omega_f) \qquad C_{LS} = \frac{4.1126}{Re_S^{0.5}} f(Re_p, Re_S)$$

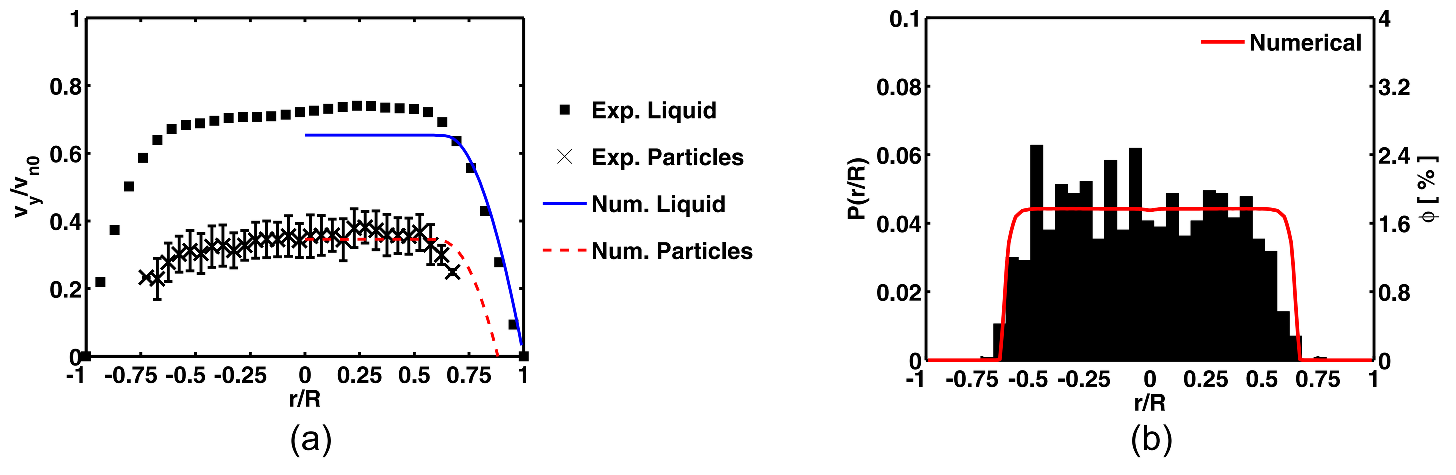
$$f(Re_p, Re_S) = \begin{cases} (1 - 0.3314\sqrt{\beta}) e^{-Re_p/10} + 0.3314\sqrt{\beta} & \text{if } Re_p \leq 40 \\ 0.0524\sqrt{\beta \, Re_p} & \text{if } Re_p > 40 \end{cases}$$

$$Re_p = \frac{\rho_f \, d_p \, |u_f - u_p|}{\mu_f} \qquad Re_S = \frac{\rho_f \, d_p^2 \, |\omega_f|}{\mu_f} \qquad \beta = 0.5 \frac{Re_S}{Re_p}$$

ρ_f : fluid density d_p : particle diameter u_f : phase velocity
u_p : particle velocity $\omega_f = rot \, u_f$ μ_f : dynamic viscosity

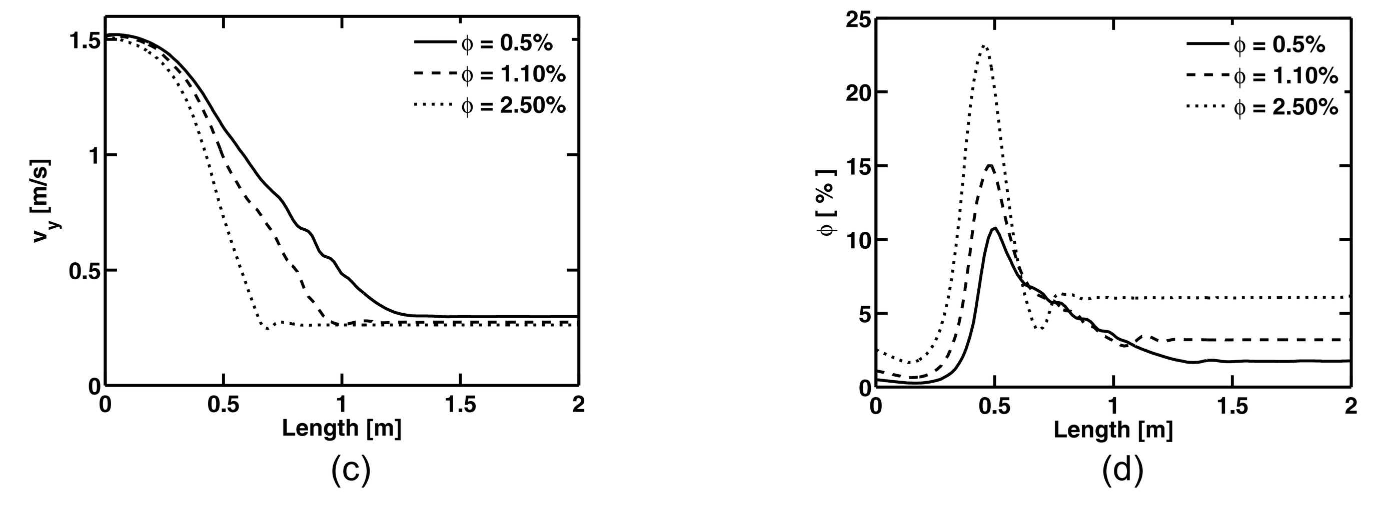
5. Results

- Comparison between measurements and numerical results for a monodisperse suspension (exp. #10 in [2]):



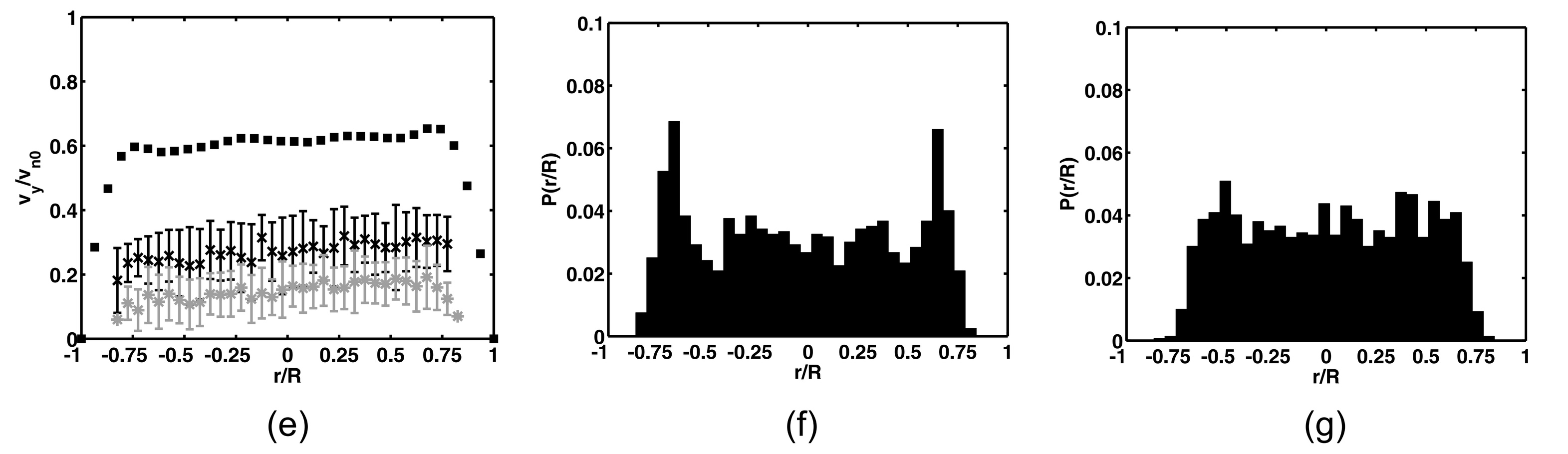
(a) fluid and particle velocities at 1.6 meters from the entrance and (b) particle distributions and concentrations at the same position

- Numerical results of the concentrations and fluid velocities along the axis for d_p = 4 mm particles and Re_c = 285:



(c) fluid velocities along the axis and (d) particle concentrations along the axis

- Measurements for a bidisperse suspension (exp. #20 in [2]):



(e) x, average vertical velocities of the 4 mm particles, I, standard deviation for 4 mm particles, *, average vertical velocities of the 5 mm particles, I, standard deviation for 5 mm particles, ■ , fluid average velocity, (f) particle distribution ϕ_4 = 0.62% and (g) particle distribution ϕ_5 = 0.50%.

6. Conclusions

- It was possible to measure solid-liquid mono- and bidisperse suspensions using matched refractive index.
- Comparisons between experiments and numerical approach show fairly good agreement.
- Simulations of monodisperse suspensions predict axial accumulation of particles in front of the entrance.
- The lateral concentration peaks observed in bidisperse suspensions could be explained by the interplay of analogous axial accumulations and muti-particle lift forces.

References

[1] E. Michaelides: Particles, bubbles & drops (2006).
[2] R. Aragall and G. Brenner: Detailed quantification of dispersed particles transport through PIV and PTV measuring technique. Proceedings of 13th Workshop on Two-Phase Flow Predictions (2012).
[3] R. Mei: An approximate expression for the shear lift force on a spherical particle at finite Reynolds number. JFM (1992).

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