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Evaluation of Energy Spectra in Bubble Driven Liquid Flows from Direct Numerical Simulations

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Introduction

- The modification of a turbulent flow by bubbles and the generation of pseudo-turbulence by bubbles rising in a laminar flow are only partly understood
- A suitable measure to quantify pseudo-turbulence and the modulation of shear-induced turbulence by bubbles is the one-dimensional power spectrum of the liquid phase velocity fluctuations
- Measurements of the spectrum slope indicate different power laws, ranging from the classical -5/3 one to a more steep -8/3 one and are not conclusive
- For evaluation of the spectrum from the measured velocity signal several methods are proposed how to bridge over the gaps due to bubble passages
- **Goal**: use velocity signals from direct numerical simulation of bubbly flows to investigate the influence of the gap-bridging method on the power spectrum

Numerical simulations

- In-house code TURBIT-VOF solves incompressible Navier-Stokes equation with surface tension by a VOF-method with local planar interface reconstruction
- Simulations of bubble driven liquid flow in a plane vertical channel with periodic boundary conditions for 2 different cases
  - A) regular bubble train (1 bubble, ε = 0.82%, grid 64^3, 60 000 time steps)
  - B) bubble swarm (8 bubbles, ε = 6.5%, grid 100^3, 120 000 time steps)
- Further simulation parameters
  - non-dim. domain 1×1×1 with d_B = 0.25
  - reference scales L_{ref} = 4m, U_{ref} = 1m/s
  - bubble Eötvös number $Eö$ = 3.06
  - Morton number $M = 3 \times 10^{-6}$
  - density ratio 0.5, viscosity ratio 1

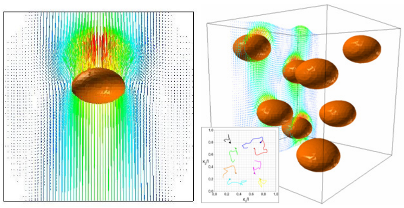

Fig. 1: Visualization of bubble train flow (left) and bubble swarm flow (right) and bubble trajectories in top view (right: inset figure).

Velocity time signals

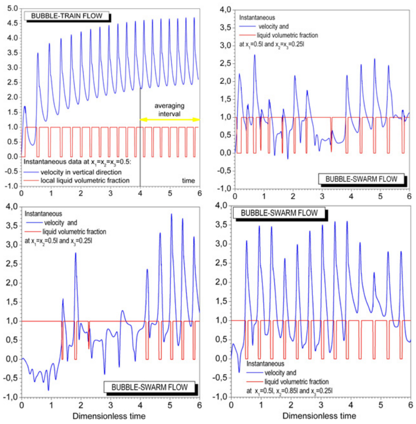

Fig. 2: Non-dimensional temporal signals of vertical velocity u_1 (blue) and liquid volume fraction (red) for bubble train and bubble swarm flow (for three different positions).

Autocorrelations $R_{11}(l\Delta t)$

- Evaluation by four different methods:
  - Method 1: eliminating the gas parts of the signal and patching together the liquid parts [1]
  - Method 2: replacing the gas parts of the signal by linear interpolation between the liquid parts [2]
  - Method 3: replacing the gas parts by the mean velocity of the liquid [3]
  - Method 4: filling the gas parts of the signal with segments having same statistical properties as the liquid [4]

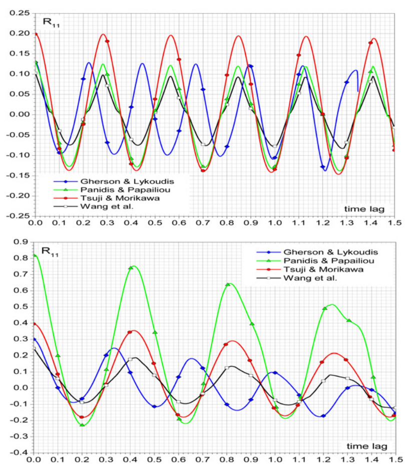

Fig. 3: Autocorrelations for bubble train flow for x_1=x_2=x_3=0.5 (top) and bubble swarm flow x_1=0.5, x_2=0.85, x_3=0.25 (bottom).

1D Energy spectra

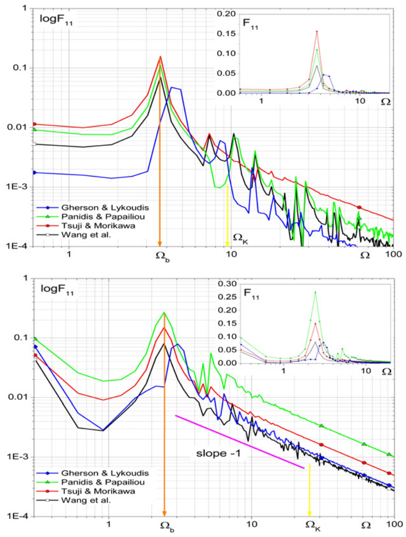

Fig. 4: 1D Energy spectrum for bubble train flow for x_1=x_2=x_3=0.5 (top) and bubble swarm flow x_1=0.5, x_2=0.85, x_3=0.25 (bottom). $1/\Omega_K$ corresponds to the Kolmogorov time scale and $1/\Omega_b$ to the average time of the bubbles for one rise through the periodic domain.

Conclusions

- Methods 2, 3 and 4 yield the correct frequency Ω_b while method 1 over-estimates it (the amount of which depends on the void fraction)
- The 1D spectrum should fulfill

$$2\int_0^\infty F_{11}(\Omega)\mathrm{d}\Omega = u^2_{1L,\mathrm{rms}}$$

  An evaluation of this relation shows that methods 2 and 4 overestimate the energy content of the spectrum
- Method 3 is recommended as it reasonably predicts the dominant frequency and the energy content of the spectrum
- The slope -1 is in agreement with dimensional considerations for pseudo-turbulence [5]

References:

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[2] Tsuji & Morikawa *JFM* 120 (1982)

[3] Wang et al. *J. Fluids Eng.* 112 (1990)

[4] Panidis & Papailiou *Int. J. Multiph. Flow* 26 (2000)

[5] Lance & Bataille *JFM* 222 (1991)

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