CFD Simulation of the Two-Phase Flow around an Obstacle applying an Inhomogeneous Multiple Bubble Size Class Approach

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Outline

1. The concept of the inhomogeneous MUSIG model
   • role of the lift force for the flow regime
2. Application to the simulation of a complex flow situation
Nondrag bubble forces: Forces perpendicular to the flow direction

• Turbulence Dispersion:
  – transfer of the turbulent fluctuations of the liquid on the bubbles
  ➢ smoothing of radial volume fraction profiles

• Wall Force:
  – pushes bubbles away from the wall

• Lift Force:
  – gaseous bubbles in a shear flow: pressure differences from the liquid surrounding on the bubble surface
  – proportional to the gradient of the liquid flow field
  ➢ direction dependent on the bubble size
Tomiyama (1998): Experimental Investigation of single bubbles in a laminar shear flow (Glycol)

\[
C_{\text{Lift}} = \begin{cases} 
\min[0.288 \tanh(0.121 \text{Re}), f(Eo_d)] & \text{for } Eo_d < 4 \\
 f(Eo_d) - 0.27 & \text{for } 4 < Eo_d < 10 \\
 -0.27 & \text{for } Eo_d > 10 
\end{cases}
\]

with \( f(Eo_d) = 0.00105 Eo_d^3 - 0.0159 Eo_d^2 - 0.0204 Eo_d + 0.474 \)

\[
Eo_d = \frac{g(\rho_l - \rho_g)d_h^2}{\sigma}
\]

- application of this correlation to air/water:
- \( C_{\text{LIFT}} \) changes the sign at \( d_B = 5.8 \text{ mm} \).
Conditions for steam/water

- evaluation of the Tomiyama correlation:
  - with higher pressure the critical bubble size \( d_B(C_{LIFT}=0) \) is decreased
Measurements in FZD: Decomposition of the gas volume fraction distribution according bubble size

Each pixel is labelled according to the size of the bubble it belongs to.

Decomposition

$D_{bl} < 5.5 \, \text{mm}$  $D_{bl} > 5.5 \, \text{mm}$
TOPFLOW experiments

\[ J_L = 1 \text{ m/s and } J_G = 0.22 \text{ m/s (FZR-118), L/D = 40, Injection valves: } D_{\text{inj}} = 4 \text{ mm} \]

Influence of bubble forces on the flow regime in a vertical upward bubbly flow

- **Lift Force:**
  - small bubbles are pushed towards the wall
  - large bubbles are moved towards the centre

- **bubble break-up**
  - turbulent dissipation
  - only near the wall

- **bubble coalescence:**
  - at bubble accumulation

> radial phenomena have important influence on the flow regime

> a model approach has to be able to describe radial separation of small and large bubbles
Population balance approach

- Definition of different bubble size classes
  - interact via models for bubble coalescence and bubble break-up
- In the Euler/Euler approach in principle the definition of several bubble classes is possible
- For the adequate description decades of bubble classes would be necessary (shown by separate investigations)
- Numerical problems: CPU time, convergence, stability
Multiple bubble size group model (MUSIG)

- S. Lo (1996 CFX-4):
  - for the gaseous phase only one velocity field
  - only one momentum equation for the gaseous phase
  - consideration of bubble break-up and coalescence only in the continuity equation
Concept for the improvement of the MUSIG Model

- The gaseous momentum equation is solved for at least two gaseous phases
- the description of the separation of small and large bubbles becomes possible
- simulation of bubble coalescence and break-up over all gaseous subsize fractions (continuity equation)
TOPFLOW FZR-118: $J_L=1.0 \text{ m/s}$, $J_G=0.2194 \text{ m/s}$

2 dispersed Phases, 34 sub-size fractions
Investigation of a complex flow situation: Flow around an obstacle
Comparison of calculated and measured timely averaged gas volume fraction and liquid velocity distributions

Run 096: $J_L = 1.017$ m/s; $J_G = 0.0898$ m/s
Calculated Turbulence Dissipation
Comparison of measured and calculated cross sectional averaged bubble size distributions

Run 096 $J_L = 1.017 \text{ m/s}; J_G = 0.0898 \text{ m/s}$
streamlines for large and small bubbles

Run 096:
\[ J_L = 1.017 \text{ m/s}; \]
\[ J_G = 0.0898 \text{ m/s} \]
Lift forces

Run 096:

\[ J_L = 1.017 \text{ m/s}; \]

\[ J_G = 0.0898 \text{ m/s} \]
mean sauter bubble diameter

Run 096:
\[ J_L = 1.017 \text{ m/s}; \]
\[ J_G = 0.0898 \text{ m/s} \]
Gas distributions for different bubble size classes run 096 ($J_L = 1.017$ m/s; $J_G = 0.0898$ m/s)

**measurement**

<table>
<thead>
<tr>
<th>VOID</th>
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<tbody>
<tr>
<td>$0.0 \leq \text{d} \leq 5.8$</td>
<td>$5.8 \leq \text{d} &lt; 200.0$</td>
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<tr>
<td>max = 7.0 %</td>
<td>max = 28.3 %</td>
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**calculation**

- $d_B < 6$ mm
- $d_B > 6$ mm
Run 097:
\[ J_L = 1.611 \text{ m/s}; \]
\[ J_G = 0.0898 \text{ m/s} \]
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Gas distributions for different bubble size classes

Run 097:
\[ J_L = 1.611 \text{ m/s}; \]
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Obstacle: Summary of observations

1. Phenomena in the wake of the obstacle
   • Small bubbles are transported behind the obstacle (lift force)
   • Bubble accumulation behind the obstacle causes coalescence
   • in the measurements behind the obstacle mainly large bubbles are found

2. Phenomena in the jet beside the obstacle in the non-obstructed cross sectional area
   • Generated large bubbles are rejected into the jet beside by the obstacle
   • Near the jet margin large shear rates are found
     • fragmentation of large bubbles (not considered in the calculations)
     • small bubbles are rejected out of the jet (lift force)
Summary

- correct function of the inhomogeneous MUSIG model approach confirmed
- thoroughly understanding of the complex flow situation
- closure models for bubble forces in agreement with experiment
- most weak point: Models for simulation of bubble coalescence and bubble break-up
  - With the actual implemented models tuning coefficients are necessary:
    - air/water in vertical tube: $F_B = 0.25; F_C = 0.05$
    - steam/water in vertical tube: $F_B = 0.02; F_C = 0.05$
    - complex flow: tuning factors depend on flow situation
- Further work is considered for future investigations