NUMERICAL MODELLING OF THE HYDRODYNAMICS IN A BUBBLE COLUMN USING THE EULER-LAGRANGE APPROACH

S. Laín, D. Bröder & M. Sommerfeld

Institut für Verfahrenstechnik. Fachbereich Ingenieurwissenschaften. Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale). Germany

Bubbly flows are found in a number of technical and industrial processes, such as sewage water purification, flotation devices, and bubble column reactors. The latter find applications as gas-liquid contactors in chemical and biochemical processes. The hydrodynamics in bubble columns is determined by the bubble rise and hence bubble size distribution and gas hold-up. Moreover, turbulence will be induced by the bubble rise due to the evolution of large scale flow structures, shear produced in the vicinity of the bubble, oscillations of the bubbles, and the wakes of the bubbles. Especially mass transfer in bubble columns will be largely affected by this small scale turbulence generated on the scale of the bubble. Although attempts have been undertaken for many years to theoretically describe the flow structure in bubble columns, in order to predict industrial processes, there is a lack of detailed physical understanding and predictive tools for design and optimisation of bubble columns. In recent years, computational fluid dynamics (CFD) has become an attractive tool for supporting process design and optimisation and hence commercial CFD tools are increasingly used by industry. For the numerical computation of two-phase flows two approaches are mainly applied, namely the Euler/Euler and the Euler/Lagrange approach. The first method considers both phases as interacting continua, while in the second method the discrete nature of the dispersed phase is taken into account by tracking a large number of individual bubbles through the flow field. Recently, numerical methods have been developed which consider the unsteady nature of the flow in bubble columns based on both the Euler/Euler[1] and the Euler/Lagrange approach[2,3]. A comparison of the performance of both approaches for the prediction of bubbly flows was recently conducted by Sokolichin et al. (1997)[4]. In all these calculations however, turbulence of the continuous phase was not considered, rather a effective viscosity was used in order to match calculated results with measurements. Moreover, in some cases the bubble motion was calculated in a rather crude fashion, by assuming a fixed slip velocity, or using a simplified slip relation, and adding some fictitious diffusion component for simulating turbulent dispersion[2,5].

Time-dependent calculations of the flow patterns evolving in a bubble column have been performed by solving the Reynolds-averaged conservation equations in a time- dependent way. The conservation equations are closed using the well-known k-ε turbulence model[6]. The dispersed phase (i.e. bubbles) is simulated in a Lagrangian way, where a large number of bubbles are tracked simultaneously through the flow field. In the equation of motion all the relevant forces, such as drag, buoyancy and gravity, added mass and pressure, and transverse lift forces are considered.

The instantaneous fluid velocity components at the bubble location, which are required to solve the equation of motion, are determined from the local mean fluid velocity interpolated from the neighbouring grid points and a fluctuating component generated by the Langevin model described by Sommerfeld et al. (1993)[7]. In this model the fluctuation velocity is composed of a correlated part from the previous time step and a random component sampled from a Gaussian distribution function. The correlated part is calculated using appropriate time and length scales of the turbulence form the k-ε turbulence model.

The ability of this procedure to compute the hydrodynamics in a small cylindrical bubble column has been assesed in a previous paper[8]. In it, the influence of the bubbles motion in the liquid is taken into account by appropiate source terms in the momentum equations[9]. In order to account for turbulence modification by the bubbles and specially for the wake induced turbulence, the source term in k- and ε-equations suggested by Crowe and Gillandt (1998)[10] was implemented. Since both phases are computed time-dependent, the evaluation of the source terms required some special treatment in order to yield reasonable averages of the source terms in each control volume where bubbles are present. Therefore, the time step to solve the fluid flow equations (i.e., the Eulerian time step) is selected to be considerably larger than the Lagrangian time step for calculating the bubble trajectories, so that the source terms are averaged over the Eulerian time step. The numerical calculations have been validated with the experiments of Bröder et al.[11], which consider a cylindrical bubble column with a diameter of 140 mm and a height of 600 mm. The diameter of the bubbles in this case was lower than 1.5 mm. In the comparisons, the mean axial and the rms values of the axial and radial bubble velocity were taken into account, providing good agreement when the bubble size pdf and drag law for fluid bubbles were considered.

However, in the deduction of Crowe and Gillandt terms only the drag force was present, while in the bubble motion equation also pressure, added mass and transverse lift forces have been introduced. In order to be consistent, all of these extra forces have been considered in the present work to account for the modification of the liquid turbulence. The simulation is performed in a fully consistent Lagragian way, which results in a robust numerical algorithm. Figure 1 shows the performance of this terms (called CT) and the usual Reynolds averaged ones (named DT).

In order to get more insights on the relevance of the different underlying mechanisms that play a role in the hydrodynamics of the bubble column, the equations that describe the liquid have been separated in their constitutive terms: temporal variation, convection, diffusion, source terms and interaction terms with the bubbles. As a result, the interaction terms are the most important ones in all the equations except in the radial velocity (where the buoyancy is not acting), being counterweighted essentially by the diffusion terms.

The numerical predictions are then compared with experimental measurements[12] for different void fractions (Figures 2 and 3). In these cases not only the mean axial and both rms components for the bubble velocity are considered but also the mean and fluctuating axial liquid velocity are taken into account showing a reasonable agreement, especially for the lower gas void fraction.

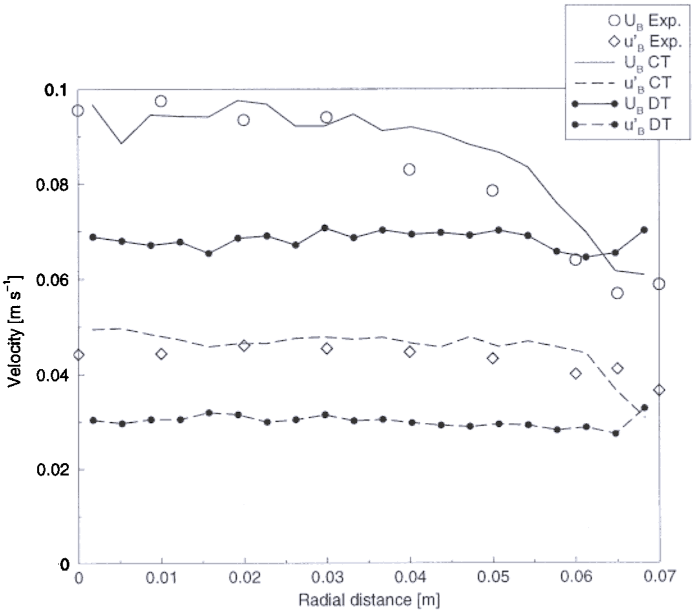

Figure 1: Performance of the full consistent bubble source terms in k and ϵ equations (CT in the plot) versus the traditional Reynolds averaged terms (DT in graphic) for a case of 0.37% gas void fraction.

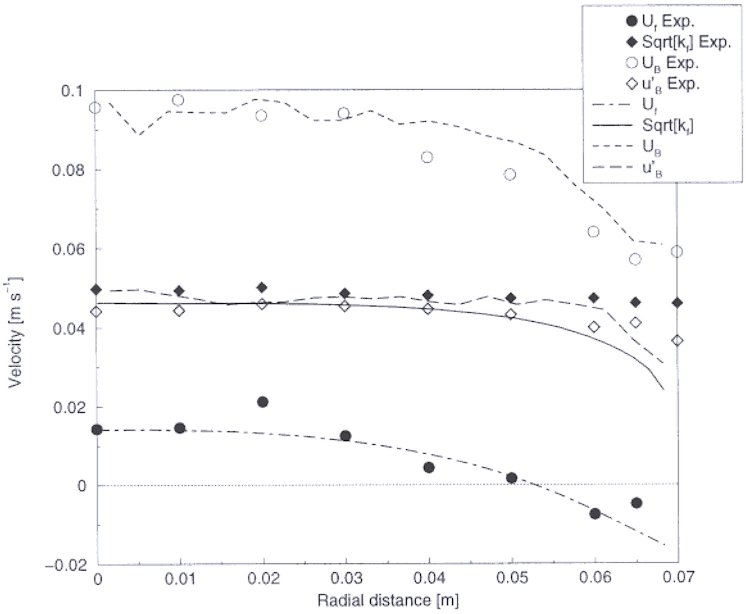

Figure 2: Mean and fluctuating axial velocities for gas and liquid phases. Case 0.37% gas void fraction.

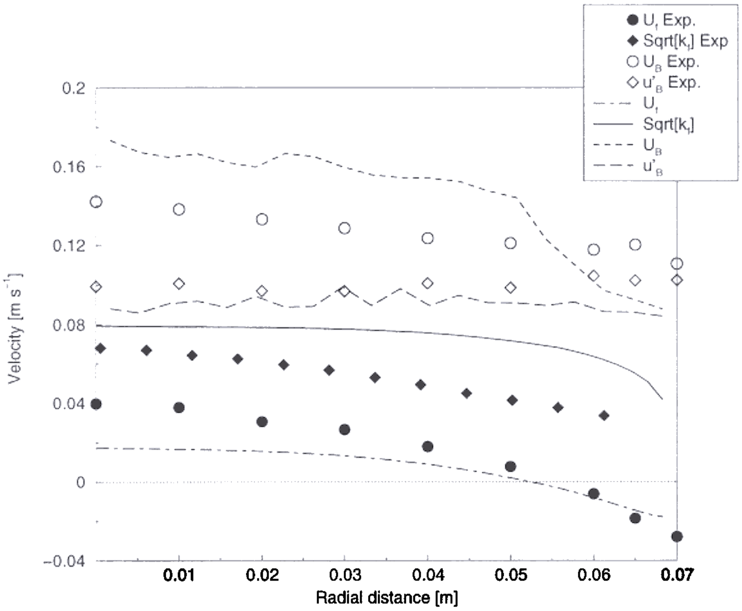

Figure 3: Mean and fluctuating axial velocities for gas and liquid phases. Case 1.31% gas void fraction.

REFERENCES

1. Sokolichin, A. and Eigenberger, G., Gas-liquid flow in bubble columns and loop reactors: Part I. Detailed modelling and numerical simulations, *Chem. Eng. Science,* Vol. 49, 5735 (1994).

2. Lapin, A. and Lübbert, A., Numerical simulation of the dynamics of two-phase gas-liquid flows in bubble columns, *Chem. Eng. Science*, Vol. 49, 3661 (1994).

3. Murai, Y. and Matsumoto, Y., Three dimensional structure of a bubble plume.Measurement of the three dimensional velocity, *Flow Visualization and Image Processing of Multiphase Systems*, ASME, FED-209, 187 (1995).

4. Sokolichin, A., Eigenberger, G., Lapin, A. and Lübbert, A., Dynamic numerical simulation of gas-liquid two-phase flows: Euler-Euler versus Euler-Lagrange, *Chem. Eng. Science*, Vol. 52, 611 (1997).

5. Sokolichin, A. and Lapin, A., Dynamic numerical simulation of turbulent bubbly flow: A fundamental approach, *Proc. Transport Phenomena in Two-Phase Flow*, Nassebar (Bulgaria), September 1998.

6. Launder, B.E. and Spalding, D.B., The numerical computation of turbulent flows, *Computation Methods in Applied Mechanics and Engineering,* Vol. 3, 269 (1974).

7. Sommerfeld, M., Kohnen, G. and Rüger, M., Some open questions and inconsistencies of Lagrangian particle dispersion models, *Proc. Ninth Symp. on Turbulent Shear Flows*, Kyoto, Japan, Paper 5.1, 1993.

8. Laín, S., Bröder, D. and Sommerfeld, M., Experimental and numerical studies of the hydrodynamics in a bubble column, *Chem. Eng. Science,* Vol. 54, 4913 (1999).

9. Sommerfeld, M., Decker, S. and Kohnen G., Time-dependent calculation of bubble columns based on the time-averaged Navier-Stokes equations with turbulence model, *Proc. Japanese-German Symp. On Multiphase Flow*, Tokyo, Japan, 323-334, 1997.

10. Crowe, C.T. and Gillandt I., Turbulence modulation of fluid-particle flows. A basic approach, *Proc. of the 3rd Int. Conf. On Multiphase Flow*, Lyon (France), June 1998.

11. Bröder, D., Sommerfeld, M. and Tisler, S., Analysis of the hydrodynamics in a bubble column by phase-doppler anemometry, *Proc. of the 3rd Int. Conf. On Multiphase Flow*, Lyon (France), June 1998.

12. Sommerfeld, M. and Bröder, D., Untersuchung der Hydrodynamik einer Blasensäule mittels der Phasen-Doppler-Anemometry, *Proc. Lasermethoden in der Strömungsmesstechnik* GALA, paper 35 (1999).