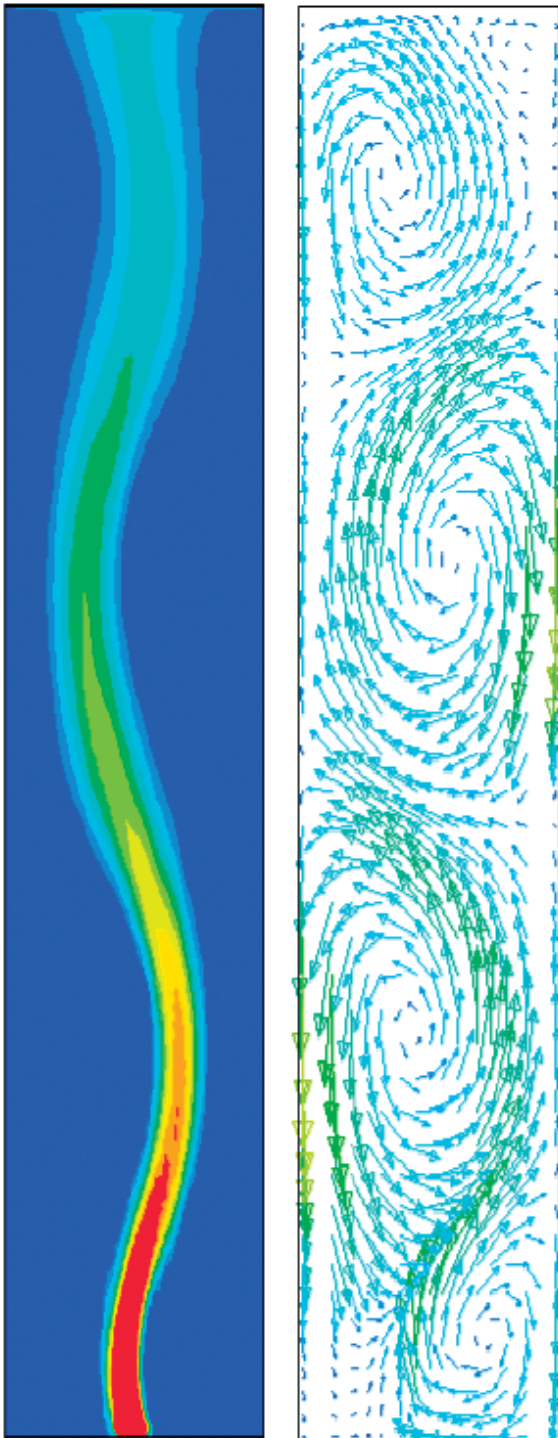


Bubbling Columns

By Vivek V. Buwa and Vivek V. Ranade, Industrial Flow Modeling Group, National Chemical Laboratory, Pune, India



Instantaneous gas volume fraction (left) and liquid velocity vectors (right) for a superficial gas velocity of 0.14 cm/sec, simulated using a single-group Eulerian multiphase model (H/W: 4.5)

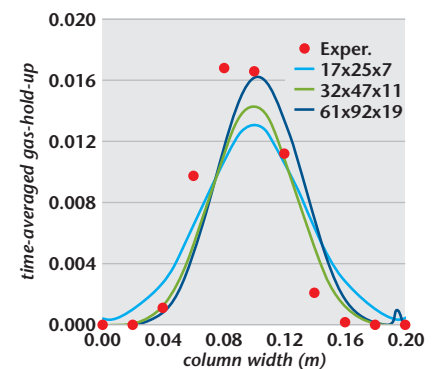
Unsteady multiphase flows are frequently encountered in chemical process equipment. Bubble column reactors, even though simple in construction, are characterized by a host of inherently unsteady complex flow processes with widely varying scales of space and time. For example, recirculating reactor-scale flow processes coexist with microscopic flow processes around individual bubbles. The overall multiphase fluid dynamics controls the fluid mixing and inter-phase transport processes, which in turn determine the reactor performance. Most of the early work in this area was focused on predicting time-averaged flow properties with the help of a few adjustable parameters. While time-averaged characteristics can help provide general guidelines for reactor design, the effects of the unsteady flow characteristics are lost. Experimentally validated CFD models need to be developed, therefore, for accurate prediction of the dynamics of gas-liquid flows in bubble columns.

At the National Chemical Laboratory, a rectangular bubble column has been constructed for this purpose. Its geometric simplicity allows for systematic experiments and numerical simulations with minimal computational demands. The specific geometry was chosen to complement earlier experimental work¹. A jet of air, injected at the center of the base of the water-filled column, gives rise to a meandering plume of bubbles. Wall pressure fluctuations have been recorded to characterize low frequency oscillations that correspond to local recirculating flow. The effect of various design and operating parameters on the plume oscillation period has been investigated. In addition to wall pressure fluctuation measurements, single-tip voidage probes have been used to record the local instantaneous void fraction.

CFD simulations of the bubble column have been performed using several multiphase approaches. The Eulerian multiphase model in FLUENT was initially used to simulate the 3D, unsteady gas-liquid flow. Each of these so-called "single-group" simulations used water for the primary phase and a single secondary phase of air bubbles represented by an average bubble diameter.

A set of simulations was performed to study the effects of superficial gas velocity, sparger configuration (including bubble diameter), and the height-to-width (H/W) ratio of the column on the low frequency oscillations and time-averaged flow variables, such as vertical liquid velocity and gas hold-up. The results indicated that the dynamic characteristics are sensitive to bubble size, as produced by different sparger configurations. See Reference 2 for additional details of experimental measurements and CFD simulations.

The single-group findings prompted the launch of a project to develop a multi-group, or multi-fluid model based on a discrete population balance methodology. The population balance model, which accounts for bubble coalescence and break-up, was developed and mapped onto FLUENT through user-defined functions. While developing population balance models, it is essential to ensure the conservation of certain properties of the bubble population. During coalescence and break-up processes, 1) the mass of bubbles should be conserved, 2) the number of bubbles should be appropriately reduced or increased, and 3) the interfacial area should be appropriately reduced or increased. Since bubble population is represented by a finite number of groups, it is difficult to satisfy all of these three conditions simultaneously. Thus, in this work, mass conservation and adjustments to the bubble number were incorporated in the population balance models, but adjustments to the interfacial area were



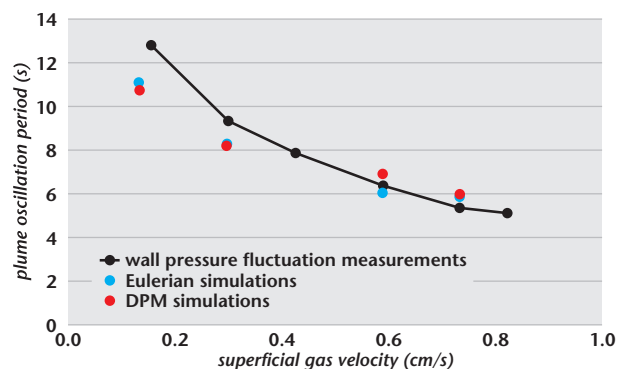
Time-averaged gas holdup calculations show the dependence on grid density (Superficial gas velocity: 0.14 cm/s, H/W: 2.25)

not. With this approximation, the maximum error in predicted interfacial area is about 10% for the smallest group, and it decreases for larger groups. The model has been used to study the evolution of the bubble size distribution in bubble column reactors, and has shown reasonably good agreement with experimental measurements. The results are encouraging and the model is being extended to various other multiphase systems, such as stirred tank reactors. These models can be easily extended to simulate gas-liquid mass transfer.

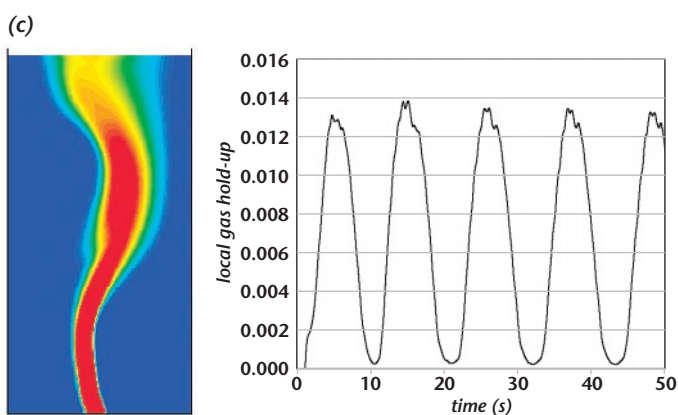
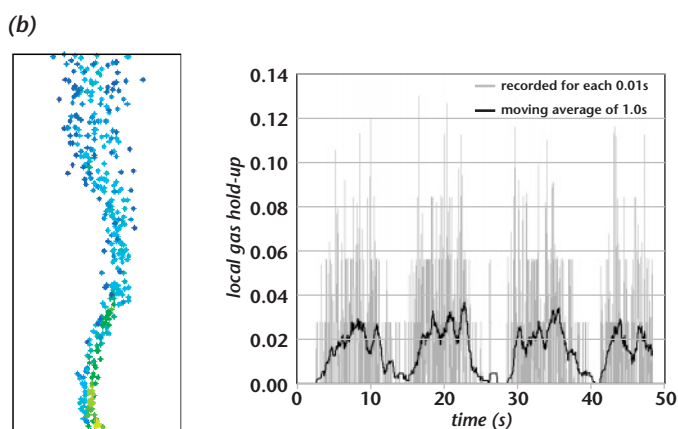
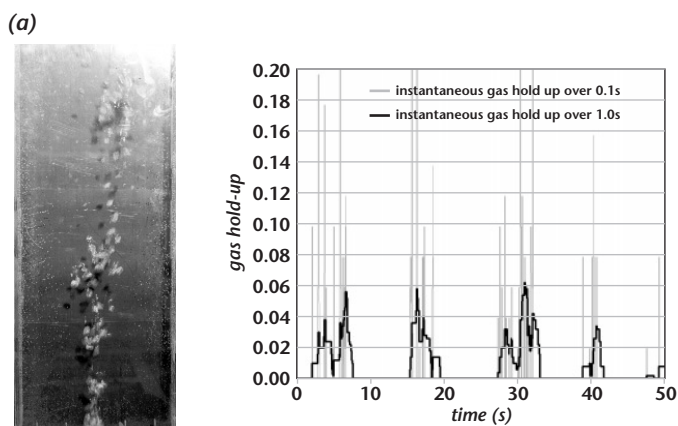
In another set of simulations, the Lagrangian discrete phase model (DPM) in FLUENT was used to follow the motion of individual bubbles. This approach provides information on bubble scale processes, which is necessary for any rigorous modeling of reactions and heat and mass transfer. The simulation results have been validated against experimental measurements. For example, the plume oscillation period calculated from the numerically predicted voidage fluctuation time series using DPM simulations agrees well with the experimental measurements and Eulerian simulations. The time-averaged vertical liquid velocity (based on LDA measurements¹) and gas hold-up measured at different column heights are in reasonably good agreement with both the Eulerian and DPM approaches. The power spectrum of bubble passage frequencies obtained by the transient DPM simulations also shows good agreement with experimentally measured bubble passage frequencies.

Gas-liquid and gas-liquid-solids flows in cylindrical bubble columns have also been studied. The gas-liquid flow was found to be highly chaotic in comparison to the quasi-periodic flow observed in the rectangular bubble column. Single-group simulations using the Eulerian multiphase model were carried out for the gas-liquid mixtures, and a few three-phase simulations (with gas, liquid, and granular phases) were carried out for the gas-liquid-solids mixtures to study the effect of solids loading on key dynamic and time-averaged flow properties. The results, which have been compared to measurements, are still preliminary but are encouraging. They will be used in the future to help clarify the dynamics of complex multiphase flows in bubble columns.

In another set of simulations, CFD models were used to predict mixing time, an important parameter for reactor engineering. In these simulations, the liquid phase mixing was simulated using transient and time-averaged flow. The mixing time values obtained using time-averaged flow were found to be much larger than those obtained by fully transient flow. For example, at a superficial gas velocity of 0.14 cm/s, the mixing time obtained using time averaged flow was 26.2 s in comparison with 15.4 s obtained using unsteady flow. The latter agrees well with the experimentally measured mixing time of 16.0 s. The effects of H/W ratio, sparger configurations, and gas velocities on the liquid phase mixing time have been investigated using CFD as well, and the results have been validated using experimental measurements. ■



The plume oscillation period predicted by the Eulerian multiphase and discrete phase models, compared to experiment (H/W:2.25)



Instantaneous bubble/gas volume fraction distribution and corresponding voidage fluctuation time series obtained from (a) experiments, (b) DPM, and (c) Eulerian multiphase simulations (Superficial gas velocity: 0.14 cm/s, H/W: 2.25)

References

- Pfleger D., Gomes S., Gilbert N., and Wagner H.-G., "Hydrodynamic simulations of laboratory scale bubble columns fundamental studies of the Eulerian-Eulerian modeling approach," *Chemical Engineering Science*, 54, p. 5091-5099, 1999.
- Buwa V.V. and Ranade V.V., "Dynamics of gas-liquid flow in a rectangular bubble column: Experiments and single/multi-group CFD simulations," *Chemical Engineering Science*, 57, p. 4715-4736, 2002.