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Industrial applications with Eulerian approach

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1 Introduction

The main objective of this lecture is to complement the theory lecture presented earlier with practical examples of applying the models to the analyses of industrial multiphase flows. Real life experiences of carrying out multiphase flow CFD analyses are shared with the readers.

The selected examples include:
(1) solid-liquid flows in stirred vessels,
(2) gas-liquid flows in a bubble columns,
(3) gas-liquid flows in aeration tanks,
(4) gas-solid flows in fluidised bed reactors,
(5) gas-liquid flows in boiling reactors.

2 Solid-liquid flows in stirred vessels

Many processes in the pharmaceutical, chemical and related industries involve suspensions of solid particles in liquids. To prevent settling of particles, the mixtures are stirred by impellers so that uniform distribution of particles is maintained. The question often asked by the plant operators is "What is the optimum speed for the stirrers?"

Researchers at University of Palermo has carried out a series of experiments [1] in order to provide suitable data for validating CFD models can predict correctly the particle suspension level at different stirrer speeds.

Comparisons between the computed and the experimental results show that the particle suspension levels at three different stirrer speeds (300, 380 and 480 rpm) are in good agreement. The conclusion we can draw from this exercise is that CFD models can correctly predict the particle suspension level in a stirred vessel.

It is a good practice to check whether the CFD results are independent of the grid spacing used. The grid independence results show that the coarse grid model (12474 cells) has under-predicted the suspension level. The results demonstrate that it is important to have sufficient grid density to resolve the flow properly and that grid independence check should be carried out whenever possible.

The inter-phase forces between the particles and the liquid include: buoyancy, drag, turbulence drag, lift and virtual mass forces. The effects of these forces on the solution were investigated and found that lift and virtual mass forces were negligible. The buoyancy and drag forces are the dominant forces. However, the turbulence drag force which accounts for the dispersion of the particles due to turbulence must be included, otherwise the suspension level will be under-predicted.

3 Gas-liquid flows in bubble columns

It is well known that flows inside bubble columns are highly unsteady. Therefore it is not surprising that three-dimensional transient analyses are required for modelling flows in bubble columns. Measured data such as void fraction and velocity profiles from experiments would usually have some forms of averaging applied to the data sampled over a time period. In order to compare results obtained from CFD calculations against measured data, the CFD results also need to be averaged in a similar way.

The experimental work of Hills [2] provided good sets of measured data for the validation of our CFD models for bubble columns. Measured profiles of void fraction and liquid velocity for a range of flow rates and different gas distributors are available for comparison with computational results. We carried out three-dimensional transient calculations for selected cases described by Hills. The computed results for a series of time instances were saved and later used to produce a time-averaged result of the computed flow solutions. The time-averaged result was further averaged azimuthally to give radial profiles of void fraction and velocities. The comparisons of these profiles have shown good matches between the computed and measured results.

From the averaging process we can also analyse the statistical quantities such as standard deviation of the data to indicate the variability of the flow in the column. We have also investigated several drag force correlations and found that the model by Tomiyama [3] gave the best agreement between the computed and measured results.

4 Gas-liquid flows in aeration tanks

Rectangular aeration tanks are commonly used in the water industry in wastewater treatments. Oxygen required for biological processes is supplied to the water by injecting air bubbles into the water. A simple homemade model of an aeration tank was made using a domestic fish tank and air injectors. Photographs of the flows in the tank were taken and used for comparisons with the computed results.

“Degassing” boundary was used to model the free surface where the air bubbles are allowed to escape due to buoyancy but for the water the boundary acts like a frictionless wall.

In examining the vector plots, we need to remember that the transport equations are solved for all cells so that in regions where the local volume fraction is near zero, the velocities are not necessary zero. One way to present vector plots is to colour the vectors by the local volume fraction so that regions with near zero volume fraction can be ignored.