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ABSTRACT

Bubble columns are widely used for carrying out reactions and mass transfer operations in chemical, pharmaceutical and biochemical processes. This thesis concerns the modeling of the characteristics for bubble column reactors in order to provide the basis for solving the engineering problems such as design, scale-up and process control of the reactors.

(1) Based on the theories of molecular collision and isotropic turbulence, a semi-theoretical model with only one unknown parameter for the rate of bubble coalescence in turbulent gas-liquid dispersions is developed in Chapter 3, using an empirical (or semi-theoretical) coalescence efficiency function of the coalescence time and the interaction time. This model includes the effect of size ratio between two bubbles and has been used to determine the bubble size distribution in a bubble column, together with the bubble breakup rate model and the population balance model. It may be used to the liquid-liquid dispersions. No experimental results are available in the literature to confirm this model.

(2) A theoretical bubble or drop breakup rate model without any unknown parameters is proposed also in Chapter 3, based on the principles of molecular collision, isotropic turbulence and probability. Unlike most of the previous work, this model does not need to assume a daughter bubble or drop size distribution and the daughter size distribution can be obtained directly from the model. The predicted daughter bubble or drop size distributions by this model have shown very good agreement with the experimental results of Hesketh *et al.* (1991a).

(3) In Chapter 4, the parallel film concept is extended to develop two theoretical models for the approach between two equal or unequal sized fluid particles. A simple model gives expressions for the film area and the interaction time. The

latter is needed for determining the coalescence efficiency in the bubble coalescence rate model in Chapter 3. A more general model can only give numerical solutions for the film area and the interaction time. The predicted film areas by the general model are in concordance with the experimental data of Scheele and Leng (1971), but those by the simple model are not good. Both models give similar results for the interaction time and do not coincide with the experimental data very well. The detailed analysis for the data shows that the deviations may be caused by the oscillations of the particles themselves.

(4) A one-dimensional population balance model is proposed in Chapter 5 for predicting local bubble size distributions in bubble columns. In this model, the coalescence and breakup rate models are used. This model has an unknown parameter which is from that in the coalescence rate model. The predicted results above the entrance region for the air-water system in a tall bubble column by the model are in reasonable agreement with the measured results by the five-point conductivity probe technique. This model shows that, for the air-water system, the bubble size distribution above the entrance region of the column is not sensitive to the bubble sizes formed by the gas distributor.

(5) In Chapter 6, the pseudo-homogeneous fluid concept, which has been frequently used for modeling the liquid circulation in bubble columns but has also been often mixed with the two-fluid concept, has been clarified by this work. An analytical expression for the radial liquid velocity profile has been derived from this concept, using a radial turbulent viscosity distribution in single-phase pipeline flows and an empirical expression for the radial gas holdup distribution in bubble columns.

A new two-fluid model for the liquid circulation has been proposed. Unlike the previous two-fluid models, the assumption that the shear stresses in liquid phase and bubble phase are equal, is not used, because this assumption is found to be unreasonable not only in physical meaning but also in the same equation of motion obtained as the pseudo-homogeneous concept. The new two-fluid model can also give analytical expression for the liquid velocity profile, using the same distributions for turbulent viscosity and gas holdup as in the pseudo-homogeneous model.

These two models are easy and fast to use, and are in good agreement with the experimental data reported in the literature. Since these models have not ignored the effect of molecular viscosity, they can also give good predictions even for high viscosity liquids. The pseudo-homogeneous model is simpler but needs to tune the gas holdup distribution parameter, m, to the experimental data. The two-fluid model is better in physical concept and usually need not to tune the parameter, m.

(6) A new model for determining bubble sizes and specific interfacial areas in bubble columns by the dynamic gas disengagement technique is developed in Chapter 7, based on a concept of non-uniform steady state distribution of the bubble dispersion. Interpreting the non-uniformity in the axial direction, this model using the DGD technique gives axial gas holdup distributions, and by assuming an axially homogeneous dispersion, a radial gas holdup distribution can be obtained. The Sauter mean diameters and specific interfacial areas for several gas-liquid systems have been estimated by the model and the DGD technique. The results in the air-water system are compared and are in agreement with those measured by a five-point conductivity probe technique. The obtained axial gas holdup distributions agree well with those measured by Menzel (1989) and the radial gas holdup distributions for the same system are also in reasonable agreement with those measured in this work. Results are also reported for the air-salt water, air-aqueous propanol and air-dodecylbenzene systems.

(7) The principles and measurements for using the five-point electrical conductivity probe technique are discussed in Chapter 2. By using this technique, bubble size distributions, bubble velocities and movement directions, and local gas holdups in the air-water system have been measured. These data have been used for verifying the modeling work.

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