Qi X-B, Ph.D., “Studies on the Fluid Dynamics of Circulating Fluidized Bed Risers”, Sichuan University, May 2003.

Abstract

The gas-solid two-phase flow in circulating fluidized bed (CFB) risers presents highly complicated hydrodynamic aspects. Although numerous research efforts have led to significant advances in the understanding of hydrodynamics from the macro-distributions of gas-solid flow structure to the micro-behaviors of particle clustering, further studies are obviously needed in order to make clear the inherent mechanisms of various phenomena exhibiting in gas-solid two-phase flow so that more reliable models and scale-up methods of CFB reactors can be developed.

This work conducted systematic experimental measurements of local solids holdups and particle velocities as well as the axial pressure gradients. The experiments were carried out under wide operation conditions with FCC and sand particles. Two experimental CFB risers were used in the work, both having the same diameter of 100mm, but different heights of 15.1m and 10.5m, respectively. Based on the measured data, intensive analytical work was conducted to investigate the effects if particle properties and geometric structure on hydrodynamic gas-solid flow in risers and the inherent relationship between local and overall flow structures.

Significant effects of riser height on the distribution of axial pressure gradients were found. Under the same operating condition, the axial distribution of solids holdups in a higher riser are much more uniform than those in a lower riser. It is suggests the effects of riser height must be taken into account when developing the gas-solid two-phase flow hydrodynamic model and the scale-up method of CFB reactors, although many experimental conclusions and correlations in past work were based on a single riser and thus did not pay sufficient attention to this problem.

Under certain operating conditions, the flow of sand particles (belonging to group B of Geldart’s classification) will show a phenomenon of deceleration after the effect of gas distributor disappears. Under low gas velocity conditions ($U_g<5.5$m/s), the axial and radial distributions of FCC are much more uniform than those of FCC.

Based upon the systematical experimental data obtained in this study and from other literatures, it is found that under the operating conditions with the same modified solids-to-air flow ratio $G_s^{1.2}/G_g^{2.0}$, the gas-solid two-phase flows in risers show a very similar macro distribution and micro behaviors. This gives way to develop new model parameters so that the behaviors of gas-solid two-phase flows in CFB riser reactors can be described more exactly.

The pressure drop due to this friction between the gas-solid suspension and the wall was quantitatively analyzed, and by referring to the fluid flow in circular pipe, a model was proposed to predict the pressure drop of gas-solid flow in fully developed section of risers. This model includes particle and gas properties, riser structure parameters, and operating parameters. The predicted results are in good agreement with the experimental data.

Taken into account of the the effect of riser height, particle properties, and the friction between gas-solid suspension and the wall on solids holdups, a correlation was proposed to predict the solids holdup in fully developed region of CFB risers. The correlation explains the differences among the predicated values of other correlations and delineates more clearly the variations of solids holdups in fully developed region with operation parameters, ratio of riser height to diameter, particle properties, the friction between gas-solid suspension and the wall.

The experiment shows that under various operating conditions, the local solids holdups, particle velocities and solids fluxes reach the corresponding cross-sectional average values at $r/R \approx 0.8$, and consequently the dimensionless radius of the core region can be defined as $r/R = 0.8$. Preliminary studies show that this dimensionless radius is independent of particle properties, superficial gas velocity, solids circulation rate, and axial height.

The data analysis shows that the gas-solid flow in the annulus is much more sensitive to the changes of operating parameters and particle properties than that at the core region, indicating that the overall variations of gas-solid flow on the whole cross section of riser with the changes of operating parameters, particle properties, and axial location is mostly due to the variation in the annular region.

Based on the transient data of local solids holdups, cluster properties (cluster frequency, existence time, solids holdup within cluster and vertical size) and the distributions of these parameters in axial and radial directions are intensively studied, revealing to some extent the inherent relationship between local and overall flow structures. Results show that the axial and radial non-uniform distributions of solids holdups and particle velocities are closely connected with the axial and radial variations of transient cluster properties such as cluster size, shape, velocity, frequency, existence time, solids developments of transient cluster properties, and core-annulus flow structure is the reflection of different behaviors of clusters at core and annular regions.