

Zhang H, Ph.D., "Hydrodynamics of a Gas-Solids Downflow Fluidized Bed Reactor", The University of Western Ontario, September 1999.

Abstract

Experiments were carried out in a specially designed 5 m high, The hydrodynamics of gas-solids downflow fluidized bed reactor were systematically studied in a 9.3 m tall and 0.1 m i.d. circulating fluidized bed downer reactor using FCC particles. The radial distributions of the local solids holdups and the local particle velocities as well as the pressure gradients along the downer column were measured to characterize the local and overall gas-solids flow structures. These three parameters were measured using a fiber optic solids concentration probe, a fiber optic particle velocity probe and a series of pressure transducers respectively. Local solids fluxes were also calculated from the local particle velocities and solids holdups.

Results show that the radial distributions of particle velocity, solids holdup and solids flux in a downer reactor are much more uniform than those in a riser. For most of the conditions tested, the gas-solids flow takes about 5 to 8 m from the top entrance to become fully developed while the particles needs about 1 to 4 meters to be fully accelerated. However, under certain conditions, the development section can extend to as long as or beyond the 9.3 m downer.

In order to characterize the gas-solids flow structure under zero superficial gas velocity conditions, the radial distributions of the local solids holdups and particle velocities along the downer column were measured with the superficial gas velocity set to zero. A flow structure characterized by an uniform radial solids holdup distribution in the core and a non-uniform radial distribution in the annulus where the solids holdup increases towards the wall. This unique gas-solids flow structure is completely different from that at high gas velocities. The gas-solids flow pattern under zero gas velocity conditions, together with that under low gas velocity conditions, can be considered as a special regime (named the "dense-annulus flow regime"). This differs from the regime under high gas velocity conditions (named the "dense-core flow regime").

Based upon the theoretical analyses and the systematical experimental data obtained in this study, a semi-empirical model is proposed to predict the radial profiles of particle velocity and solids holdup for the fully developed flow in a downflow fluidized bed. For the "dense-core flow regime" that occurs under higher gas velocity conditions (~ 5.7 m/s), the radial distributions of particle velocity and solids holdup can be well predicted by this model. The simplicity of the model makes it possible for potential industrial applications. For the "dense-annulus flow regime" that appears under low superficial gas velocities ($< \sim 5.7$ m/s), a different flow regime is present in the downer so that the turbulent flow model does not provide the best prediction.

Comprehensive comparisons are made in a circulating fluidized bed riser/downer system between a 15.1 m high, 0.10 m i.d. riser and a 9.3 m high, 0.10 m i.d. downer. It shows that the radial and axial flow structures in the downer differ largely from that in the riser. Both the macro flow structure (the radial and axial distributions of solids holdup and particle velocity) and the micro flow structure in the downer are much more uniform than those in the riser. This ensures a low backmixing, a narrow RTD and a high gas-solids contact efficiency in the downer. These key

properties of the downer make it a very promising candidate for industrial applications where short reaction times and high product selectivity are required.

In order to ensure precise measurements of local solids concentration, the fiber optic solids concentration probe was accurately calibrated using a novel calibration technique. This technique includes more defined and variable measurement limits (by using different "black boxes") to optimize the measurements for different flow densities, and an iteration procedure utilized to eliminate calibration error caused by the non-linear relationship between the solids concentration and voltage output.

A new fibre-optic probe system was characterized for the direct measurement of the local velocity of particles in gas-solids flow suspension. This five-fibre optical probe measures local particle velocities using a peak-to-peak detection technique and automatically determines and discards the false signals. It can also simultaneously measure the velocities of upflowing particles and downflowing particles. It is proven that the novel five-fibre optical probe is a promising system for measuring the movement of solid particles in the circulating fluidized bed and other gas-solids flow systems.