HYDRODYNAMICS OF GAS-SOLID TURBULENT FLUIDIZED BEDS

by

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ABSTRACT

Many commercial fluidized bed processes (e.g. catalytic and gas-solid reactions, drying) operate in the turbulent fluidization flow regime owing to its excellent gas-solids contacting, favourable heat transfer, and relatively low axial dispersion of gas. The flow characteristics of turbulent fluidized beds, having transient voids and a diffuse bed surface, have not been well defined, and there have been relatively few previous studies on the fundamental hydrodynamics of this industrially important flow regime. In this research project, four different size fluidized beds – 0.11 m, 0.29 m, 0.61 m and 1.56 m in diameter – with Fluid Cracking Catalyst and a commercial catalyst, all involving Geldart Group A particles, have been used to investigate the effect of reactor size, system pressure and temperature on U_c, the superficial gas velocity corresponding to the onset of the turbulent fluidization flow regime, and on the local flow structure for different superficial gas velocities beyond U_c.

The transition velocity, U_c, from the bubbling to the turbulent flow regime was deduced by measuring the pressure fluctuations in the bed using gauge and differential pressure transducers. Results show a different trend of column diameter, D, on U_c between shallow ($H/D < 3$) and deep beds ($H/D \geq 3$). U_c from differential pressure measurements was a stronger function of the height of the pressure cell compared to the effect of radial position for the 1.56 m fluidization column. The transition velocity decreased with increasing system pressure (to 0.4 MPa) confirming findings by earlier investigators. Increasing temperature (to 240°C) led to a decrease in the transition velocity. The amplitude of the differential pressure fluctuations indicated very little change in void size with changing temperature for the range investigated. U_c from differential pressure signals decreased with increasing height above the distributor plate. This implied greater homogeneity at the top of the bed. Spectral analysis of differential pressure signals at different axial positions revealed a shift towards lower frequencies with increasing height. Once the turbulent fluidization flow regime was achieved, the dominant frequency becomes less sensitive to height.

Axial pressure profiles indicated diffuse bed surfaces. The gauge pressure in the freeboard increased with increasing superficial gas velocity due to solids entrainment. The bed expansion depended on the configuration of the solids collection and return system. In systems where the solids circulation rate was not controlled, the characterization of the overall operating conditions in terms of bed voidage becomes difficult. Increases in both absolute pressure and temperature were found to increase bed voidage, with pressure having a greater influence than temperature.

Local voidages were measured experimentally by means of optical fiber and capacitance probes. The signals indicated continuous probability distribution functions and rapid fluctuations, indicating a breakdown of the discrete-two-phase structure, i.e., discrete dense and dilute phases, a common feature of the bubbling bed flow regime. Cycle times obtained from rescaled range analysis of voidage signals suggested a range of cycle frequencies similar to those detected by the dominant peak from spectral analyses.

A recently established optical velocity probe capable of simultaneously measuring particle velocity and voidage was used to delineate the change in the local two-phase flow structure when the superficial gas velocity was increased beyond U_c. Void velocities deduced from cross-correlation of voidage signals obtained from two identical optical voidage probes were shown to become increasingly sensitive to the threshold value separating the dense and dilute phases. Hence the utility of the two-phase theory in characterizing void dynamics in the turbulent fluidization flow regime became limited. De-noising voidage fluctuation signals using a nonlinear wavelet transform through soft thresholding was shown to be successful in pre-conditioning the signal for cross-correlation of bivariate time series.

This study provides further understanding of the hydrodynamics of the turbulent fluidization flow regime using equipment of substantial size to determine transition velocities and provide hydrodynamic data which are meaningful for industrial-sized fluidized beds.