Issangya AS, Ph.D., "Flow Dynamics in High-Density Circulating Fluidized Beds", The University of British Columbia, March 1998 (co-supervised, JR Grace of UBC as chief advisor).

Abstract

Almost all previous circulating fluidized bed hydrodynamic data reported in the literature have been for suspension densities and solids circulation rates well below values used in fluid catalytic cracking and other catalytic reactors. A dual-loop circulating fluidized bed unit capable of achieving solids hold-ups as high as 15 to 25% by volume over the entire riser and solids circulation fluxes of 400 kf/m^2s and beyond was designed and constructed. Measurements were obtained in a riser of inside diameter 76.2 mm and height 6.1 m at superficial air velocities between 4 and 8 m/s with FCC particles of mean diameter 70 m m and density 1600 kg/m^3.

Longitudinal solids hold-up profiles, inferred from differential pressures, showed that a dense zone formed when the solids circulation rate exceeded the saturation carrying capacity of the gas. On further increasing the solids circulation rate, the solids volumetric concentration levelled off at 0.2 ± 0.05 while the height of the dense zone continued to expand. Low density (LDCFB) conditions are delineated from high density CFB (HDCFB) conditions by a transition point, defined as the intersection of the two linear portions when solids hold-up is plotted against solids circulation rate. Cross-sectional solids hold-ups in HDCFB conditions are not significantly affected by the superficial gas velocity. Average slip velocities are as high as 40 times the single particle terminal velocity, with slip factors as high as 15. The total pressure drop across the riser increases linearly with solids-to-gas mass flow ratio, then levels off once the dense zone occupies the whole riser. Correlations are suggested for longitudinal mean solids hold-up profiles. At a fixed solids circulation rate and air velocity, increasing solids inventories in the downcomer do not affect suspension densities in the risers.

Reflective-type optical fiber probes were employed to measure radial local voidage profiles. A non-linear relationship between the reflected light intensity and voidage was obtained using a new calibration method. Local time-mean voidages for high density conditions were nearly as low as e mf at the wall and as high as 0.9 at the axis. Local voidages were correlated as a function of the cross-sectional mean voidage, with the correlation covering a broader range of conditions than previous correlations. Visual observations indicate that solid refluxing, observed near the wall of dilute CFB risers, no longer exists for high density conditions; instead the whole suspension appears relatively homogeneous.

Radial profiles of local solids flux were measured using a suction tube for upflow fluxes and an included tube for downflowing solids. Net solids flux profiles are roughly parabolic and indicate the net flow to be, on average, upwards over the entire cross-section. Measurements from a solids momentum probe confirm that solids rise rapidly in the core and slowly near the wall. Local voidages, voidage frequency distributions, intermittency indices and voidage spectral density are also used to characterize the local flow dynamics. The core is a relatively uniform dilute flow interspersed with particle structures whose frequency and density increase with radius. The standard deviation of local voidage fluctuations reaches a peak at some distance from the wall. The location of the peak is quite different from the core-annulus boundary for LDCFB risers.

Intermittency vs. local voidage plots are "bell-shaped", with a maximum when the local time-mean voidage is approximately 0.75. The fast fluidization regime is redefined to incorporate the HDCFB findings of this study.

A novel method is also developed to determine the accumulative (Type A) and classical (Type C) choking velocities in a single experiment in the dual-loop system.