Zhang J-P, Ph.D., "Bubble Columns and Three-Phase Fluidized Beds: Flow Regimes and Bubble Characteristics", The University of British Columbia, August 1996 (co-supervised for the first 2 years, N Epstein of UBC as chief advisor).

Abstract

Experiments were carried out in three-phase fluidized beds containing solid particles contacted by upward cocurrent flow of air and water, to study flow patterns of gas-liquid-solid systems.

The minimum fluidization velocity and the particle transport velocity in a gas-liquid-solid mixture delineate the boundaries between three types of flow systems - fixed bed, fluidized bed and transport flow. Both of these velocities were measured for a variety of particles. A theoretical model, the Gas-Perturbed Liquid Model, was developed to predict the minimum liquid fluidization velocity of a bed of solid particles in the presence of a fixed cocurrent superficial gas velocity. This model, together with an appropriate equation for the gas holdup on a solids-free basis, shows almost as good agreement with the present experimental data and those from the literature as the best available empirical equation for the minimum liquid fluidization velocity at low to intermediate superficial gas velocity, and has the advantage of correctly reducing to the Wen-Yu equation for minimum two-phase fluidization as the superficial gas velocity goes to zero. Two types of particle movement were observed as the superficial liquid velocity approaches the particle transport velocity. For 1.2 mm steel shot, clusters of particles were found in both liquid-solid and gas-liquid-solid systems. For 1.5 and 4.5 mm glass beads, on the other hand, no particle clusters were observed. In the latter case, a mathematical model, the Particle Transport Velocity Model, was developed to predict the superficial liquid velocity for particle transport in upward gas-liquid flow. An empirical correlation was also proposed for the transition from fluidized bed to particle transport flow. Both predictions showed good agreement with experimental data obtained in the present work and in the literature for a wide range of superficial gas velocities.

Within the fluidized bed, based on bubble characteristics, dispersed bubble flow, discrete bubble flow, coalesced bubble flow, slug flow, churn flow, bridging flow and annular flow regimes were identified and characterized, at different combinations of gas and liquid superficial velocities. These flow regimes were also observed for two-phase air-water systems.

A comprehensive measurement method using a conductivity probe was developed to determine flow regime transitions based on bubble frequency, Sauter mean bubble chord length and the time taken by a bubble to pass a given point. Criteria for determining flow regime transitions were developed in an air-water two-phase system and then successfully applied to gas-liquid-solid three-phase fluidized beds. Flow regime maps were derived based on experimental data for three different three-phase systems. As in two-phase gas-liquid systems, churn flow, bridging flow and annular flow can be observed at high gas velocities in three-phase fluidized beds. Empirical correlations were developed to predict the flow regime boundaries in the three-phase fluidized systems investigated.