Characteristics of Gas-Liquid-Solid Fluidization with Nonwettable Particles

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In three-phase fluidized beds, it has been long recognized that the surface properties of the solid particles have significant effects on the bed hydrodynamics (Bhatia et al., 1972). Published data on three-phase fluidized beds involving air and water deal mostly with wettable particles such as glass beads; very little is associated with nonwettable particles (Fan, 1989). A typical industrial example involving nonwettable particles is in minerals flotation where a dispersant is utilized to render the solids surface nonwettable for solids separation (e.g., Bavarian et al., 1990).

The nonwettable particles tend to cluster at the liquid-gas interface due to their hydrophobic property. Thus, large-particle-bubble aggregates can be formed, causing a drastic change in the hydrodynamic behavior in the bed. Bhatia et al. (1972) reported that a liquid-solid fluidized bed with 1-mm Teflon-coated glass beads (nonwettable particles) expanded on introducing gas, whereas an initial bed contraction was observed in a bed of 1-mm wettable glass beads. Armstrong et al. (1976) observed adhesion of air bubbles to 6-mm Teflon-coated glass beads, fluidized by water. They suggested that this phenomenon of bubble adhesion to the particles led to a decrease in the apparent density of the particle, which in turn was responsible for a larger bed expansion and smaller gas holdup compared with wettable particle systems. Chen and Fan (1989) studied bubble breakage due to collision with a particle, either wettable or nonwettable, in a liquid medium. The effect of particle wettability on bubble breakage was accounted for by considering different contact surfaces between the bubble and particles of different wettability. The wettability effect was also reflected in the force interaction during collision. Based on the mechanism, it was shown that for particles of same size and density, the nonwettable one was more likely to penetrate the bubble. Fan and Tsuchiya (1990) investigated the influence of particle wettability on the dynamics of a single bubble and its wake. Experiments were performed with 460- and 774-μm Teflon-coated glass beads. Both particles were found to be attached to the bubble. The particle-bubble attachment increased the apparent weight of the bubble, as indicated by the reduced bubble rise velocity and wake shedding frequency. Godbole et al. (1990) studied the effects of poorly wettable polystyrene particles on the volumetric mass transfer coefficient in a salt-free carboxymethyl cellulose solution and in a 0.8-M sodium sulfite solution. Suspending these polymer particles in a bubble column was found to cause particle agglomeration at the gas-liquid interface, which reduced the mass transfer area as well as liquid-side mass transfer coefficient.

This study addresses the flow behavior of multibubble systems with nonwettable particles and classifies the flow pattern according to the motion of the particle-bubble aggregates.

Experimental Studies

Experiments are carried out in a Plexiglas column of 74.6-mm ID and 1.29 m in height. Water and air are used as liquid and gas phases, respectively. The liquid enters the distributor from the bottom and flows through a number of circular tubes. This flow arrangement ensures uniform distribution of liquid in the column. Air enters the distributor from two diametrically opposite sides and flows upward. It passes through orifices before reaching the column. Teflon-coated glass beads of 774-μm-dia. are employed as the nonwettable particles. The particle density is 2,500 kg/m^3 and its terminal velocity is 0.12 m/s.

In the experiments, the superficial gas velocity varies from 0.0057 to 0.076 m/s, while the liquid velocity varies from 0.0026 to 0.045 m/s. Effects of liquid and gas velocities on the particle flow pattern are studied.

Results and Discussion

Based on the behavior of particle motion, the flow patterns in the three-phase fluidized-bed system can be classified as:

- Fixed bed
- Aggregated fluidization
- Dispersed fluidization
- Transport.

A map of these flow patterns is shown in a plot of the liquid velocity vs. the gas velocity, Figure 1. At low gas and liquid velocities, most of the particles in the bed form aggregates, and no fluidization is observed (fixed bed). Based on the em-

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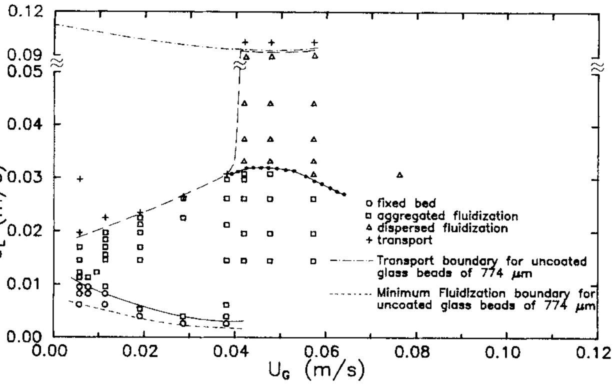

Figure 1. Flow pattern diagram in gas-liquid-solid fluidization with Teflon-coated glass beads of 774 μm.

pirical correlation of Song et al. (1989), the minimum fluidization velocity for uncoated glass beads (wettable particles) of 774 μm is obtained and found to be smaller than that for coated glass beads, for a given gas velocity. Figure 1 also shows the minimum fluidization boundary for both the coated and uncoated glass beads of 774 μm.

As the liquid velocity increases, the bed expands and the particle-bubble aggregates are fluidized (aggregated fluidization). At low gas velocities ($U_G < 0.038$ m/s), bubbles are observed to be covered by a monolayer of particles forming particle-bubble aggregates. Some aggregates are suspended in the bed without rising upward due to an increase in the apparent weight of the bubble. No coalescence of bubble aggregates is evident. A noticeable segregation of aggregates occurs in the bed. Larger aggregates move to the top of the bed because of a lower density. Some aggregates are even larger (about 5 mm) and remain suspended in the freeboard region. The number of aggregates suspended in the freeboard region increases with an increase in the liquid velocity. This behavior yields an ill-defined boundary between the dense bed and the freeboard region.

At high gas velocities ($U_G > 0.038$ m/s), bubble coalescence takes place and hence large bubbles are formed. For large bubbles, the attachment of particles is observed only at the bubble base, due to the fact that the fluid shear induced by fast-rising bubbles impedes particle attachment on the bubble roof. The bubble-base wobbling action also causes the detachment of particles from the bubble surface. Thus, for a given liquid velocity, the number of particle-bubble aggregates decreases as the gas velocity increases. Furthermore, with increasing liquid velocity, turbulence in the bed increases and more particle-bubble aggregates disintegrate into individual particles. Hence, at high gas and liquid velocities, the particles are fluidized in dispersed state (dispersed fluidization).

As the liquid velocity further increases beyond the terminal velocity of the dispersed particle or the heaviest particle-bubble aggregate at a given gas velocity, all the particles or the aggregates are transported upward and entrained from the system (transport). The transport boundary for uncoated glass beads of the same size was reported by Jean and Fan (1987) as shown in Figure 1. The liquid velocity for this boundary at low gas velocities ($U_G < 0.038$ m/s) is substantially higher than that for the coated particles. At high gas velocities ($U_G > 0.038$ m/s), however, the liquid velocity for this boundary is practically identical to that for the coated particles, reflecting the domination of hydrodynamic forces over the particle surface force under this flow condition.

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Notation

U_G = superficial gas velocity, m/s
U_L = superficial liquid velocity, m/s

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