Hydrodynamic studies of three-phase semi-fluidized beds with irregular particles

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In the present work, hydrodynamic characteristics viz. pressure drop and top packed bed of a co-current gas-liquid-solid semi-fluidized bed have been studied using liquid as continuous phase and gas as discrete phase. Experiments have been conducted in a 100 mm ID, 1.8 m height vertical perspex column using air, water and lime stone in order to develop a good understanding of each flow regime in gas-liquid-solid semi-fluidization. It is observed that pressure drop increases with increase in particle size, expansion ratio and superficial gas velocity. The minimum liquid semi-fluidization velocity increases with particle size and bed expansion ratio but decreases with superficial gas velocity. The height of top backed bed decreases with particle size but increases with liquid and gas velocities.

Keywords: Bed expansion ratio, Hydrodynamic study, Pressure drop, Semi-fluidization velocity, Three-phase semi-fluidization

Semi-fluidization is a novel fluid-solid contacting technique. The increasing popularity of semi-fluidized beds is because of its unique operation in overcoming some inherent disadvantages of both fluidized and fixed beds. Gas-liquid-solid semi-fluidization is defined as an operation in which a bed of solid particles is suspended in upward flowing media gas and/or liquid due to the net gravitational force on the particles and the motion of the particles is restricted by a top restraint. Various authors including Fan and Wen1, Roy and Sharma2, Chern et al.3, Murthy and Roy4 and Ho et al.5 have enumerated advantages of the semi-fluidized beds relating to studies on hydrodynamics, reaction kinetics, mass transfer and other unit operations. A semi-fluidized bed is characterized by a fluidized bed and a fixed bed in series within a single contacting vessel. The internal structure of a semi-fluidized bed can easily be altered to create an optimal operating configuration. This unique feature of a semi-fluidized bed allows it to be utilized for a wide range of physical, chemical and biochemical applications.

For successful design and operation of such reactors, the knowledge of parameters, such as pressure drop, minimum semi-fluidization velocity and top packed bed formation are required6,7. The study of semi-fluidized bed has been broadly classified as the prediction of minimum and maximum semi-fluidization velocities, the prediction of top packed bed height, and the prediction of pressure drop across the semi-fluidized bed.

In the present study, experiments have been conducted for the prediction of hydrodynamic behavior such as pressure drop across the semi-fluidized bed and minimum semi-fluidization velocity in which co-current flow of air and water takes place in a bed of limestone particles of various sizes.

Experimental Procedure

A schematic representation of the experimental setup is shown in Fig. 1. The vertical perspex fluidizer column is of 100 mm ID with a maximum height of 1.8 m. The column consists of three sections, viz. the gas-liquid distributor section, test section and gas-liquid disengagement section. The gas-liquid...
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A distributor is located at the bottom of the test section and is designed in such a manner that uniform distribution of the liquid and gas can be maintained in the column. The distributor section is a conical frustum of 14 cm in height, with diameter of 5.1 cm and 8 cm at the two ends and having liquid inlets. A perforated plate of 23 cm ID 1 mm thick, 11.5 cm diameter, of about 300 numbers of 2, 2.5 and 3 mm perforations is placed at the top of this section. There is an air sparger consisting of 48 numbers of 1 mm perforations in triangular pitch. In this section, the gas and liquid streams get mixed and passed through the perforated grid. Bed pressure drop has been measured using U-tube mercury manometers.

Lime stone particles (density 2552 kg/m$^3$, particle size (dp) 1.67, 2.18, 2.58, 3.07 and 4.05 × 10$^{-3}$ m), water (average temp. 30°C, density 995.7 kg/m$^3$, viscosity 0.0998 Pa.s, fluidizing media) and compressed air (oil free, average temp. 30°C, density 1.166 kg/m$^3$, viscosity 0.0019 Pa.s, fluidizing media) have been used as solid, liquid and gas phases respectively. Mercury was also used at 30°C average temperature with 13600 kg/m$^3$ density as manometric fluid. The flow of air and water is concurrent and upward. Accurately weighed amount of materials was charged into the column and adjusted for some initial static bed height. The liquid flow rate is varied for constant gas flow rate using the control valves and bypass adjustment. The bed pressure drop is measured from manometer reading. To predict the minimum and maximum semi-fluidization velocity, bed pressure drop and bed expansion are noted. Bed parameters for experimental conditions used were: initial static bed height (hs) 15, 17, 21, 25, 29 cm and bed expansion ratio (R) 2, 2.5, 3, 3.5.

**Results and Discussion**

**Pressure drop and minimum semi-fluidization velocity**

The minimum semi-fluidization velocity or onset velocity of semi-fluidization is defined as the fluid velocity at which first particle of the bed just touches the top restraint. The minimum semi-fluidization velocity in this study is obtained by visually observing the onset of semi-fluidization when the first particle touches the top restraint. Figure 2 shows the variation in pressure drop and superficial liquid velocity at various superficial gas velocities for a gas-liquid-solid system. For a particular superficial liquid velocity, higher pressure drop is observed with higher gas velocity.

![Figure 2 - Variation in bed pressure drop with superficial liquid velocity at different fixed values of gas velocity for 4.05 mm limestone at R=2.5 and hs=0.17 m](image2)

**Fig. 2—Variation in bed pressure drop with superficial liquid velocity at different fixed values of gas velocity for 4.05 mm limestone at R=2.5 and hs=0.17 m**

Figure 3 shows the variation in pressure drop with superficial liquid velocity at constant gas velocity, particle size and static bed height for different bed expansion ratios. The expansion ratio in the semi-fluidized bed is defined as the ratio of the height of top grid to the initial static bed height of the solid particles. The pressure drop is more for low expansion ratio for the same liquid velocity due to higher packed bed formation. The minimum liquid semi-fluidization velocity increases with expansion ratio.

![Figure 3 - Variation in bed pressure drop with superficial liquid velocity for different expansion ratio and particle sizes of limestone=4.05 mm at R=2.5, hs=0.17 m and Ug=0.076 m/s](image3)

**Fig. 3—Variation in bed pressure drop with superficial liquid velocity for different expansion ratio and particle sizes of limestone=4.05 mm at R=2.5, hs=0.17 m and Ug=0.076 m/s**
Height of top packed bed and maximum liquid semi-fluidization velocity

Due to the restriction of particle motion of fluidized bed by the top restraint a packed bed is formed at the top. Semi-fluidized bed is the combination of packed bed at the top and fluidized bed at the bottom of the column. In two-phase system there exists a clear zone in between top packed bed and bottom fluidized bed but it is negligible in three-phase fluidization. This is due to motion of gas bubbles in the bed. When all the solid particles of the bed are attached to the top restraint by varying the fluid velocity it is called maximum semi-fluidization velocity. The maximum semi-fluidization velocity can be obtained by extrapolation of the plot of hpa/hs to the value of 1.

Figure 4 shows that hpa/hs [ratio of top packed bed height (hpa) to the static bed height (hs)] increases with increase in gas velocity for a fixed liquid superficial velocity. The curve of variation of hpa/hs with superficial liquid velocity has been extrapolated to hpa/hs = 1 to get the value of maximum liquid semi fluidization velocities for different gas velocities. It has been observed from that maximum liquid semi-fluidization velocity decreases with increase in superficial gas velocity.

Conclusion

The hydrodynamic study of gas-liquid-solid semi-fluidized beds with spherical particles reveals that the pressure drop is found to increase with gas superficial velocity and decrease with bed expansion ratio for a fixed liquid superficial velocity. The minimum liquid semi-fluidization velocity is a strong function of gas superficial velocity and bed expansion ratio. hpa/hs increases with gas superficial velocity. The maximum liquid semi-fluidization velocity decreases with gas superficial velocity. Such studies are necessary before a confident and successful design and operation of three-phase semi-fluidized bed reactor can be undertaken. The present study is limited to source parameters, whereas remaining parameters will need a separate study.

References