THE SIZE OF WALL-AFFECTED BUBBLES IN PILOT SCALE FLUIDIZED BEDS

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A semicylindrical fluidized bed with a transparent flat wall has been employed to visually observe bubbles in a pilot-scale fluidized bed operating in the wall-affected bubbling regime.

The bubble size was observed to increase with height above the distributor and with increasing gas velocity above minimum fluidization.

No affect of particle size on bubble size was ovserved, and increasing the number of holes per distributor only reduced bubble sizes within 300 mm of the grid.

An expression proposed by Darton et al.[1] for truly bubbling beds was found to be applicable for the fluidized bed operating with predominantly wall-affected bubbles.

Introduction

The accurate prediction of bubble size in fluidized beds is imperative if large-scale fluidized bed processes are to be modeled precisely and fluidized bed pilot plant experiments are to be interpreted correctly.

This study investigates the effects of particle size, gas velocity, bed height, and distributor design on bubble sizes in a pilot-scale fluidized bed where wall-affected, rather than unrestricted, bubbles predominate. The method of Darton et al. has become well accepted as a tool to predict bubble sizes in truly bubbling fluidized beds, and the applicability of this method for wall-affected bubbles in small fluidized beds is tested.

Theory

The rise velocity of an isolated spherical cap bubble in a fluidized bed has been determinted by Harrison and Leung[2] to be analogous to the rise of gas bubbles through an inviscid liquid. The rise velocity varies with the square root of the bubble's equivalent diameter according to the relation :

$$U_B = 0.71\sqrt{gD_e}$$

When a swarm of bubbles rises through a fluidized bed, the velocity of each bubble is enhanced; and the following expression now applies for the bubble rise velocity.

$$U_B = (U - U_{mf}) + 0.71\sqrt{gD_e}$$

For large spherical cap bubbles, whose equivalent diameters are greater than 0.22 times the diameter of the fluidized bed, the velocity of the single bubble is now controlled by the bed diameter rather than the bubble size-- Hovmand and Davidson[3]-- as follows :

$$U_B = 0.35\sqrt{gD} \qquad \text{for} \quad D_e > 0.22D$$

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Such bubbles are often referred to as "wall-affected" bubbles.

For a swarm of wall-affected bubbles, the rise velocity can be approximated by :

$$U_B=(U-U_{mf})+0.35\sqrt{gD}$$

At large fluidization velocities or in small tubes, bubbles no longer remain spherical-capped in shape;but instead they become bullet-shaped bubbles which fill the cross-section of the containing tube. These are referred to as slugs. The onset of slugging can be loosely determined by Stewart's[4] criterion, which indicates that slugs will form for :

$$U-U_{mf}\geqq 0.07\sqrt{gD}$$

Truly slugging beds and truly bubbling beds have been well characterized in the literatures-- Hovmand and Davidson[3], and Rowe[5]-- but the intermediate regime of "wall-affected" bubbles has received little attention, even though this phenomenon is common in pilot-scale fluidized beds.

In truly bubbling fluidized beds, as bubbles rise up the bed from the distributor, smaller bubbles continually coalesce to form larger bubbles, resulting in an increase of the average bubble size with height. Darton et al. have proposed a bubble growth model for truly bubbling beds which predicts the equivalent diameter of bubbles at a given height in the bed as a function of distributor design and excess gas above minimum fluidization.

$$D_e=0.54(U-U_{mf})^{0.4}(h+4\sqrt{A_D/N})^{0.8}/g^{0.2}$$

No similar expression has been proposed for fluidized beds with largely wall-affected bubbles.

Experimental

A schematic of the experimental apparatus is shown in Figure 1 . The fluidized bed fabricated of steel is semicylindrical with an internal diameter of 147 mm and a height of 1515 mm. A

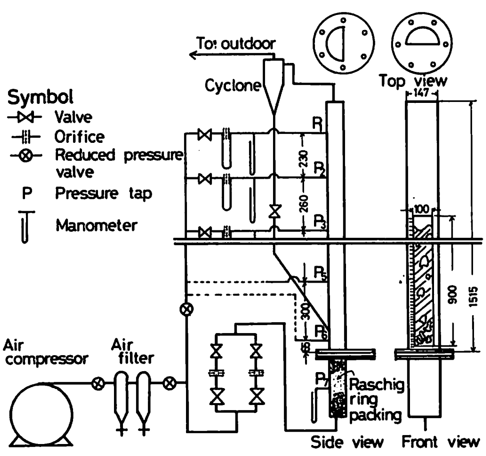

Fig. 1 Experimental apparatus

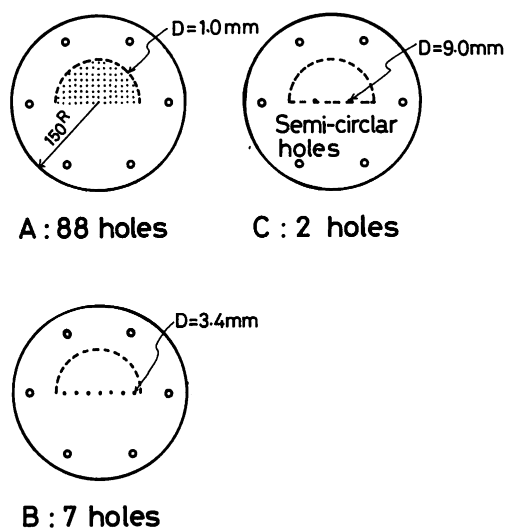

Fig. 2 Distributor (iron plate of 6. 0 mm thickness)

Pyrex glass window of size 900 mm×100 mm partially forms the flat face of the semicylindrical bed. Three perforated distributor plates were employed for the investigation, with the number of holes per plate varying from 2 to 88, as shown in Figure 2. Further details of the experimental apparatus are given by Uzu[6]. Experiments were carried out on three cuts of sand whose mean particle sizes and experimentally determined minimum fluidizing velocities are quoted in Table 1. All three sands belong to Geldart[7] Group B.

TABLE 1

SAND PARTICLES FLUIDIZED

Particle Size [μm]	U_{mf} in Ambient Air [mm/sec]
135	11.7
244	52.0
398	172

The experimental procedure to measure bubble sizes as a function of particle size, height, distributor type, and gas superficial velocity was by visual observation through the Pyrex wall of the bed. In all cases, the bed was filled with sand to a static bed height of 700 mm; and once the desired fluidization velocity had been set, 18 photographs of the bed at a given height above the distributor were taken with the aid of a stroboscope. The photographs were then analyzed to determine the average bubble size at the particular height. This whole procedure was then repeated for each sand at several heights above the distributor for a range of fluidizing velocities from 40 to 250 mm/sec.

Result

The effect of bed height on bubble size is illustrated in Figure 3 for all three sand types,

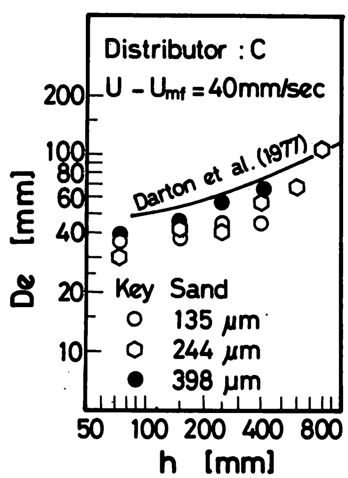

Fig. 3 Effect of particle size on D_e vs. h relation at $U-U_{mf}=40$ mm/sec

at a $(U-U_{mf})$ value of 40 mm/sec with Distributor C. In all cases, the bubbles are spherical--capped, wall-affected bubbles rather than bulletshaped slugs. Within the range of experimental error, the sizes of bubbles at a given height are independent of particle size. This is to be expected since all three sands belong to Geldart Group B--King[8]. However, bubble size increases markedly with bed height from an equivalent diameter of 30 mm at a height of 100 mm above the distributor to an equivalent diameter of 100 mm at 1000 mm above the distributor. The expression of Darton et al., plotted for comparison, gives a good estimate of the bubble sizes measured.

Figure 4 shows the variation of bubble size with height for the same three sands, with the

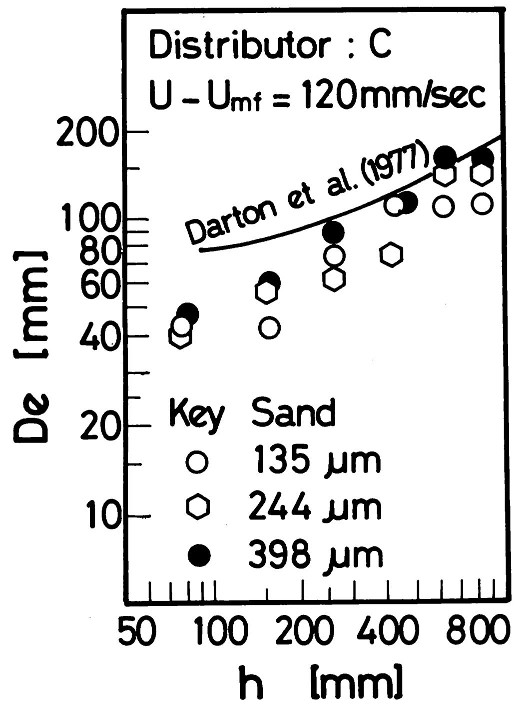

Fig. 4 Effect of particle size on D_e vs. h relation at $U-U_{mf}=120$ mm/sec

same distributor, at a higher $(U-U_{mf})$ value of 120 mm/sec. Even through Stewart's criterion indicates that slugging will occur for this bed at $(U-U_{mf})$ values in excess of 84 mm/sec, spherical-capped, wall-affected bubbles rather than slugs were still observed. As in Figure 3, the bubble sizes at a given height are independent of particle size within experimental error; and bubble size increases with bed height as predicted again by the expression of Darton et al. At this 120 mm/sec $(U-U_{mf})$ value, the average equivalent diameter of bubbles increases from 40 mm at 10 mm bed height to 140 mm at 1000 mm bed height, compared to the size increase from 30 mm to 100 mm at $(U-U_{mf})$ of 40 mm/sec. At a given height, bubble size definitely increases as $(U-U_{mf})$ increases.

The effect of the number of perforations per distributor on bubble size is demonstrated in Figure 5, where the change in bubble size with height is given for the 244 μm sand at $(U-U_{mf})$

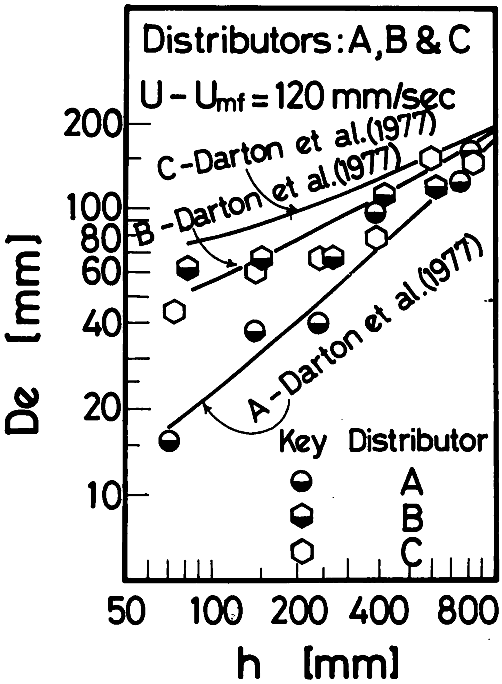

Fig. 5 Effect of Distributor on D_e vs. h relation at $U-U_{mf}=120$ mm/sec with 244 μm Sand

of 120 mm/sec for each of the three distributors. At high bed heights after bubble coalescence has been allowed to take place, no affect of distributor on bubble size is evident. However, at low bed heights below 300 mm, Distributor A with 88 perforations gives bubble sizes which are up to five times smaller tnan bubbles emanating from the other distributors with only two and seven holes. By plotting Darton et al., it is evident that their expression is capable of predicting the effects of perforated plate distributor changes on bubble size.

Conclusions

The effects of bed height, particle size, gas fluidizing velocity, and different perforated plate distributors have been investigated for a pilot-scale fluidized bed operating in the wall-affected bubble regime.

It has been found that this regime behaves in a similar manner to a truly bubbling fluidized bed, in that bubble size increases with height above the distributor and with increasing gas velocity above minimum fluidization. Particle size has no affect on the size of bubbles if particles are compared at the same excess gas velocity above minimum fluidization. Changes in distributor only affected bubble sizes within 300 mm of the distributor, where a perforated plate with 88 perforations gave much smaller bubbles than distributors with only two and seven holes.

An expression derived by Darton et al. to predict bubble sizes in truly bubbling fluidized beds has been found to be also applicable in a bed where wall-affected bubbles predominate.

List of Symbols

A_D	= distributor cross-sectional area	$[m^2]$
D	= bed diameter	[m]
D_e	= equivalent bubble diameter	[m]
g	= acceleration due to gravity	$[m/sec^2]$
h	= bed height above distributor	[m]
N	= number of holes in distributor	[−]
U	= gas superficial velocity	[m/sec]
U_B	= bubble rise velocity	[m/sec]
U_{mf}	= minimum fluidizing velocity	[m/sec]

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