Influence of Distributor Pressure Drop Uniformity on Large Fluidized-Bed Systems

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INTRODUCTION

It has been shown (Whitehead and Dent, 1967) that the initiation and maintenance of continuous solids motion contiguous to all points of gas entry at a fluidized bed distributor is critically dependent on the pressure drop between the plenum chamber and the base of the bed. Thus a high-pressure drop gas distributor is generally advantageous.

It is commonly supposed that even bubble gas distribution in a fluidized bed system can also be ensured by using a relatively high pressure drop, *uniform* resistance, gas distributor (Merry and Davidson, 1973; Agarwal et al., 1980). However, it has been shown by Whitehead et al. (1970, 1977), Werther (1977) and Geldhart and Kelsey (1968), that uniformity of gas flow across the distributor does not necessarily ensure uniformity of bubble gas distribution within the main body of a bed. This is due to the fact that, under certain specific conditions, fluidized-bed systems have definite solids recirculation patterns with bubbles rising in relatively confined streams irrespective of the uniformity of gas distribution at the bed base (Whitehead, 1979).

Merry and Davidson (1976) determined how solids circulation can be accentuated by using a *non-uniform* gas distributor (Figure 1B) and Whitehead et al. (1970) studied how to destroy the natural solids circulation using a non-uniform gas distributor (Figure 1C), Leung (1973) also suggesting such an approach. Hiby (1964) also investigated non-uniform gas distribution in small scale apparatus (Figure 1A).

It is of considerable importance to delineate conditions where distributor pressure drop and disposition can exercise control over bed circulation patterns. It is obvious that feed dispersion is governed by solids circulation patterns and it has also been shown that gas backmixing behavior is closely related to the location of downflowing solids streams (Nguyen et al., 1977).

Whitehead et al. (1970) showed that the solids circulation patterns, together with complementary bubble tracks, are related to pressure profiles developed at the bed base. Thus a measure of these pressure profiles gives an indication of the performance of the bed proper. In all the systems studied to date the more uniform the pressure profile the more even bubble activity across the bed.

In the present work, pressure profiles have been measured at the base of a bed of silica sand (Incipient fluidizing velocity U_{mf} 25 mm·s^{-1}) contained in a 2.4 m square-sided vessel fitted with variable resistance gas distributor, both uniform and nonuniform systems being studied.

The results are related to those obtained in a 1.2-m square-sided vessel and the differences in behavior in the two systems explained in terms of bubble diameter. The relevance of the criterion for distributor stability outlined by Hiby (1964) and others to large systems operated at several multiples of U_{mf} are discussed.

EXPERIMENTAL

Apparatus

The apparatus used has been described previously (Whitehead and Dent 1967) and consisted of a square-sided vessel (2.4 m × 2.4 m) fitted with 144 tuyeres of the type shown in Figure 2. The resistance to gas flow of each tuyere could be altered by varying the diameter of the orifice situated in the riser pipe. Photographic records of water manometers were used to measure the time average pressure profile developed along the diagonals (Figure 3) at the base of a 0.61 m height bed (defluidized height) of silica sand (U_{mf} 25 mm·s^{-1}, designated S.1), operating under various conditions. The technique and the properties of S.1 have been described previously (Whitehead et al., 1970).

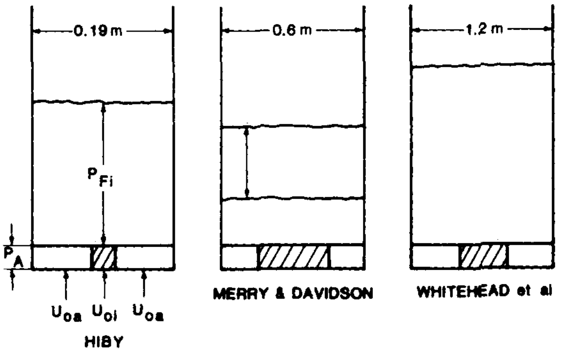

Figure 1. Apparatus previously used for non-uniform fluidization studies.

A. Hiby (1964) varied gas flow rate through the centre section (U_{oi}), and measured the bed pressure drop (P_{Fi}). P_A is the pressure drop developed over the outer section of the distributor at a gas flow rate U_{oa}.

B. Merry and Davidson (1973) kept the centre flow rate constant and used a range of higher flow rates through the outer section. Various bed depths used.

C. Whitehead et al. (1970) kept the total gas flow rate to the whole system constant but varied the ratio of the gas flows in the inner and outer sections

Method

The pressure profiles developed at distributor level were measured for three sets of uniform distributors, each having a different resistance operated at a superficial velocity of 0.24 m·s^{-1}. In a second series of experiments,

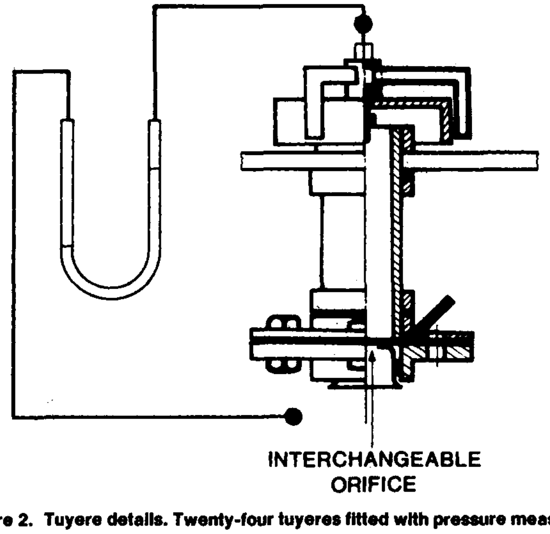

Figure 2. Tuyere details. Twenty-four tuyeres fitted with pressure measurement probes at the locations shown in Figure 3.

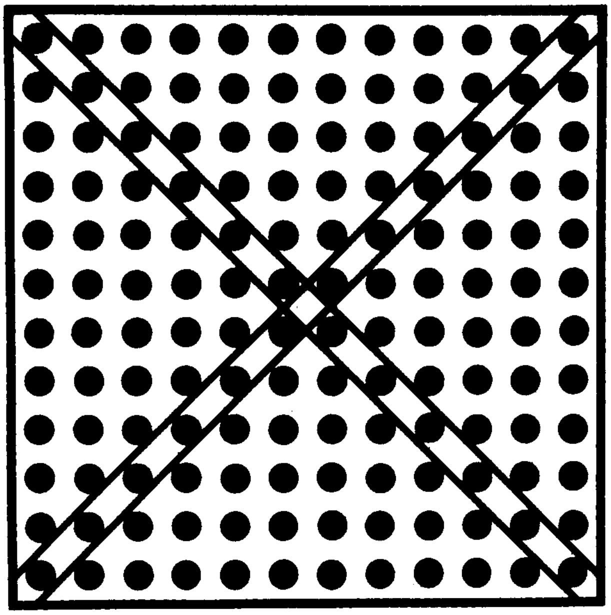

Figure 3. Location of tuyeres fitted with pressure measurement probes.

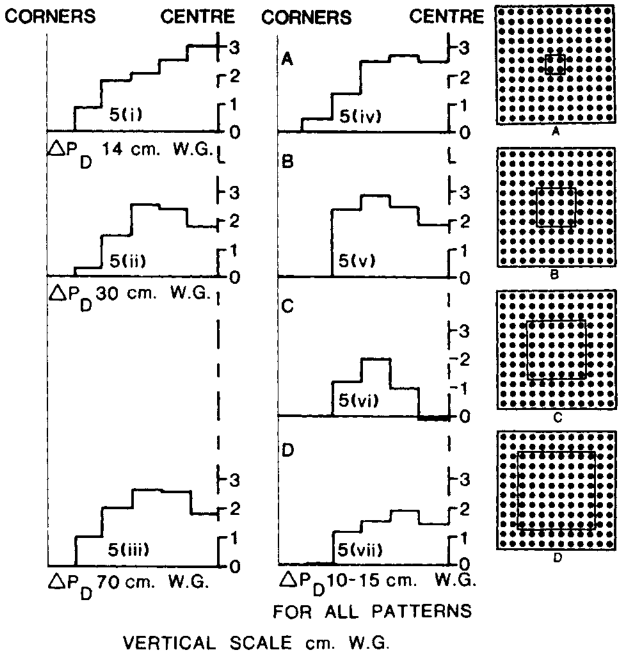

Figure 5. Pressure profiles along mean half diagonal relative to the corner tuyere. LHS shows effect of increasing resistance of a uniform distributor. RHS shows effect of increasing flow to the centre of the distributor by using an increasing proportion of low resistance tuyeres, arranged as shown, whilst maintaining a low distributor pressure drop. Total gas flow rate constant in all instances and corresponding to a mean superficial velocity 0.24 m·s^{-1} in freeboard. Silica sand U_{mf} 25 mm·s^{-1} (S1).

pressure profiles were measured for a constant average distributor pressure drop but the flow to the centre of the unit was increased by inserting larger orifices in a selected number of riser. Figure 5 shows the four arrangements used: in A the four-center tuyeres had lower resistance, in B the centre sixteen, in C the centre thirty-six, and in D the centre sixty-four.

RESULTS

Figure 5 shows the pressure profiles relative to the corner of the bed determined along a mean half diagonal for the seven conditions illustrated.

DISCUSSION

The pressure profile recorded in Figure 5(i) is characteristic of the solids circulation pattern shown in Figure 4A, i.e., a fast-moving central solids downflow dominates the system and bubbles tend to rise near the vessel periphery. This circulation has also been noted by Werther (1974) for a variety of conditions in beds with similar aspect ratio to those investigated here. Increasing the distributor pressure drop to 0.3 m WG (Figure 5 (ii)) modified the profile slightly, presumably by reducing the velocity and persistence of the central solids stream. The fluidization behavior within the vessel, however, is still far from uniform. Further increasing distributor pressure drop to 0.70 m WG did not materially alter the pressure profile, Figure 5(iii), and it is inferred that the very high distributor pressure drop, approximately 50% of the bed pressure drop, had only a minor effect on the inherent solids circulation pattern.

The situation changed considerably when non-uniformity was introduced into the distributor while retaining a low distributor pressure drop. Increasing gas flow through the central four tuyeres, Figure 5(iv), had a small effect equivalent to that induced by increasing the pressure drop of the uniform resistance distributor to 0.70 m WG. However, increasing gas flow to an increasing proportion of the tuyeres in the centre of the system resulted in more significant changes to the pressure profile. Figures 5(v) and 5(vi) were obtained with the tuyere arrangements B and C, respectively. From the pressure profile data shown in Figure 5(vi), it is inferred that the solids circulation was changed from that shown in Figure 4A to that shown in Figure 4B. Thus a low resistance, non-uniform distributor produced more effective utilization of the bed cross section than a high resistance, uniform distributor.

A further increase in the proportion of central tuyeres having an increased flow [Figure 5(vii), pattern D] resulted in a reversion of the pressure profile to that associated with solids flow shown in Figure 4A.

The present data can be compared to those previously obtained for two sets of conditions in a 1.2 m × 1.2 m vessel fitted with a similar type of gas distributor. Thus Whitehead et al. (1977) investigated the effect on pressure profile of increasing the distributor resistance five-fold when fluidizing a 1.5 m height bed of S.1 over a range of velocities. The results are shown in Figure 6 and it is seen that the pressure profile was independent of distributor resistance. This is similar to the effect noted in the present work for a uniform resistance distributor.

In earlier work Whitehead et al. (1970) increased the flow progressively to the center four tuyeres of a 36 tuyere distributor used

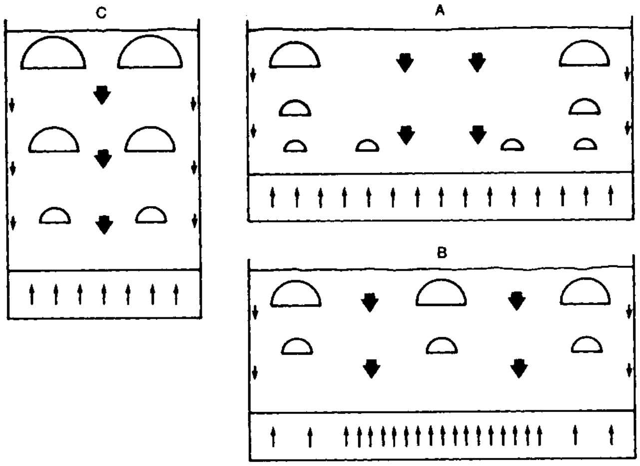

Figure 4. Solid and gas circulation patterns. Approximate bubble sizes shown to scale. A and B show circulation pattern given by uniform and non uniform distributors in present work. C shows circulation pattern in system investigated by Whitehead et al. (1970).

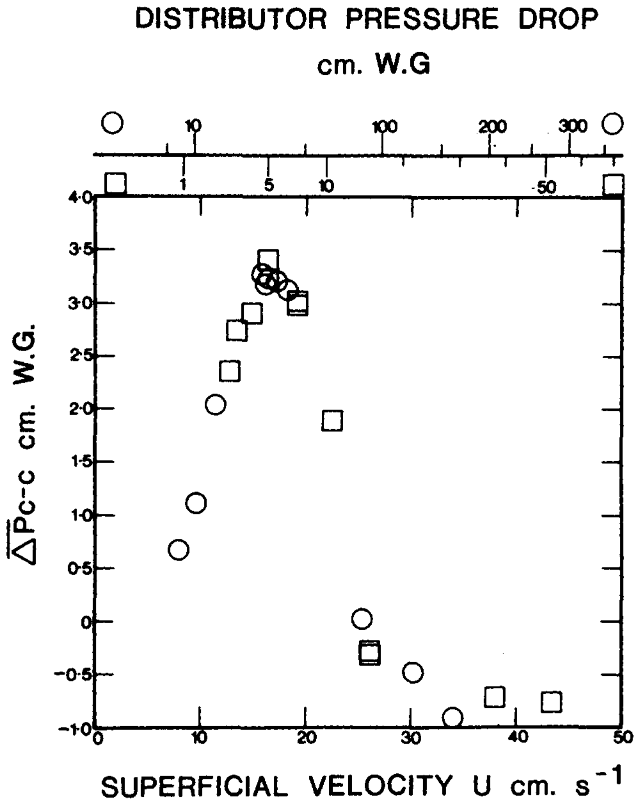

Figure 6. Relation between the mean pressure differential between the centre and corner tuyeres ($\overline{\Delta P}_c - c$) and U for bed of S1 (U_{mf} 25 mm·s^{-1}, H_0 1.5 m) contained in a square sided vessel (1.2 m × 1.2 m) fitted with 36 tuyeres. High resistance and low resistance uniform tuyere assemblies were investigated (Whitehead et al., 1977).

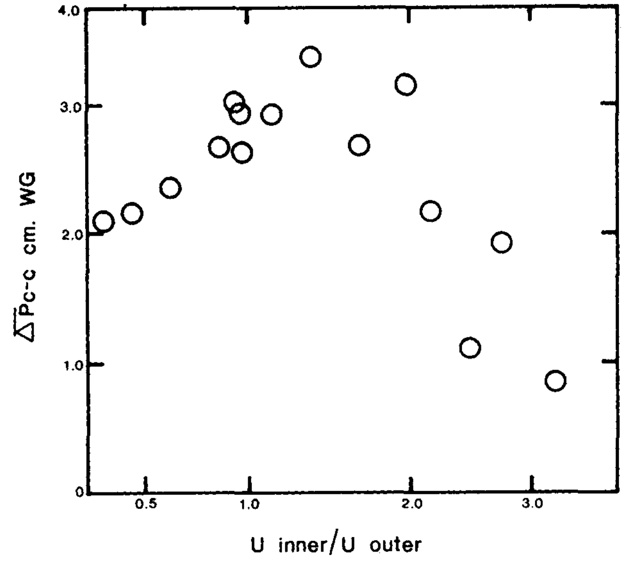

Figure 7. Effect of varying the ratio of gas flow to the inner and outer sections of a bed of S1 (U_{mf} 25 mm·s^{-1}, H_o 1.5 m) on the mean pressure differential between the center and corner tuyeres ($\overline{\Delta P}_{c-c}$). The bed was contained in a square sided vessel (1.2 m × 1.2 m) fitted with a 36 tuyere distributor. Center 4 tuyeres connected to a separate gas supply (Whitehead et al., 1970).

to fluidize a 1.5 m height bed of S.1 contained in a vessel 1.2 m × 1.2 m (Figure 1c). They found that the flow through the central four tuyeres had to be increased to 200% greater than the average flow through the rest of the tuyere assembly before the pressure profile could be significantly reduced (Figure 7). This is in marked contrast to the results reported in the present work for a larger cross-section vessel.

Data are now available (Whitehead et al., 1980) on the approximate bubble size present in the systems under consideration (Figure 8) and they afford an explanation of the various effects noted above. In the earlier work of Whitehead et al. (1970) uniform gas distribution produced the solids circulation pattern shown in Figure 4A with the surface bubbles having an approximate size shown. A 100% increase in gas flow to the central four tuyeres did not affect the pressure profile and presumably the solids circulation pattern. The extra gas was not sufficient to deflect the central stream of downflowing solids and was diverted into the four persistent bubble tracks known to exist under these conditions. Bubble size at the surface was such that a larger number of tracks could not be accommodated. Much larger gas flow imbalance produced a central bubble track and the pressure profile became uniform.

In the present work a 25% increase in gas flow to the same proportion of tuyeres effected a marked reduction in the pressure profile. The surface bubbles in this system were small in relation to bed cross section and it was possible to increase the number of bubble tracks present in the system without them interferring and combining.

The relevance of Hiby's (1964) findings on distributor stability to large systems can now be considered. He varied gas flow to the center of a bed operated at gas flows close to incipient and measured the resulting changes in bed pressure drop. Under such conditions massive solids circulation was absent and the pressure at the point of gas injection was not affected by factors other than the local distributor gas flow rate. From his results he defined distributor stability as the condition satisified when

$$\frac{dP_A}{du_{o_{crit}}} = -\frac{dP_{Fi}}{du_{oi}}$$

the symbols being defined in Figure 1(a).

The form of analysis used by Hiby has been followed by other workers such as Sigel (1976), Mori and Moriyama (1978) and Fakhima and Harrison (1970). Its use in a simplified form is probably confined to systems operated close to incipient fluidizing velocity.

In systems operated at gas flows considerably in excess of U_{mf}, solids downflow governs the movement of gas after it has passed through the distributor. Thus the form of gas flow rate-pressure drop relationship for that part of a bed located vertically above a particular section of a distributor will be dependent on whether or not downflowing solids are impinging on that section. The situation is further complicated by the time dependency of downflowing stream location.

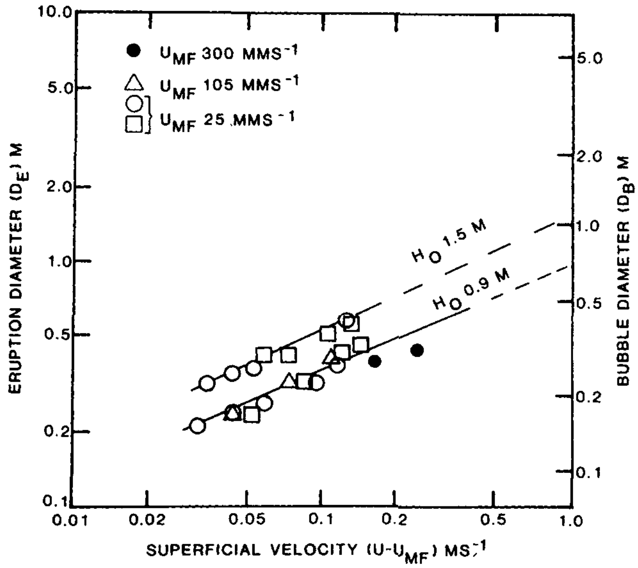

Figure 8. Effect of gas flow in excess of incipient ($U - U_{mf}$) on bubble size at the bed surface for various materials at two different defluidized bed depths (Whitehead et al., 1980).

CONCLUSIONS

High-pressure drop, uniform resistance gas distributors whilst maintaining continuity of operation do not necessarily give uniform gas distribution within fluidised beds.

Greater uniformity within the bed has been achieved by using a non uniform low flow resistance gas distributor in conditions where bed aspect ratio and fluidizing velocities were such that bubbles at the bed surface were small relative to bed width.

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