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BRIEF COMMUNICATION

INFLUENCE OF PARTICLE PROPERTIES ON THE PROPAGATION VELOCITY OF PRESSURE DISTURBANCES IN BUBBLE-FREE FLUIDIZED BEDS

D. MUSMARRA,[1] S. VACCARO,[2] M. FILLA[3] and L. MASSIMILLA[1]

[1]Dipartimento di Ingegneria Chimica, Università, Istituto di Ricerche sulla Combustione, CNR, P. le V. Tecchio, 80125 Napoli, Italy

[2]Dipartimento di Chimica, Università, via Mezzocannone 4, 80134 Napoli, Italy

[3]Istituto di Chimica Industriale, Università, via Marzolo 9, 35131 Padova, Italy

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INTRODUCTION

The propagation of pressure disturbances in a fluidized bed of 100–200 μm glass ballotini has been investigated recently by Musmarra *et al.* (1992). The bed was operated between the minimum fluidization velocity and about twice the minimum bubbling velocity. Various types of disturbances were imparted to the bed, including step compression of the bed free surface. The propagation velocity of the disturbances was determined by multipoint simultaneous measurements of instantaneous pressure (Lirag & Littman 1971; Fan *et al.* 1983; Filla *et al.* 1986; Roy *et al.* 1990).

In the range of experimental conditions investigated the propagation velocities were found to vary between 15 and 30 m/s. The dynamic wave nature of the disturbances was proved experimentally (Musmarra *et al.* 1992). A fair agreement was found between the experimental propagation velocities and predictions based on a pseudo-homogeneous model (Wood 1941; Wallis 1969; Roy *et al.* 1990) when the superficial velocities were above minimum fluidization.

The present work has been directed to characterize the influence of the density and the size of the bed solids on the propagation velocity of pressure waves in bubble-free fluidized beds perturbed by step compression of the free surface.

EXPERIMENTAL

The experimental apparatus (figure 1) is that used by Musmarra *et al.* (1992). It is made of a Perspex cylindrical column 0.10 m i.d. and 1.2 m high. It is equipped with 10 vertically aligned and 0.10 m spaced pressure taps on the wall. The bed height was 1.05 m in all runs, while the superficial velocity U was varied between the minimum fluidization velocity U_{mf} and that at minimum bubbling U_{mb}.

The characteristics of the bed materials are listed in table 1. They cover ranges of particle size d_p and density ρ_p from group A to group D of Geldart's (1973) classification. The properties of materials indicated as B–A and B–D are those of solids close to the boundaries between region B and region A, and between region B and region D. The measured minimum fluidization and minimum bubbling velocities are reported in table 1, together with the width of the interval between the bed voidage at minimum fluidization ε_{mf} and that at minimum bubbling ε_{mb}. The interval shrinks, moving from finer and lighter to coarser and heavier particles. It eventually vanishes for B–D and D solids.

Impulsive disturbances were obtained by means of a pneumatically driven gas permeable piston. The maximum stroke allowed by the apparatus was 0.07 m. The actual stroke was limited by bed compaction at $\varepsilon = \varepsilon_{mf}$. The full stroke was reached when porous silica or porous alumina were fluidized in the column at $\varepsilon \simeq \varepsilon_{mb}$. The stroke reduced to few millimeters when group D particles

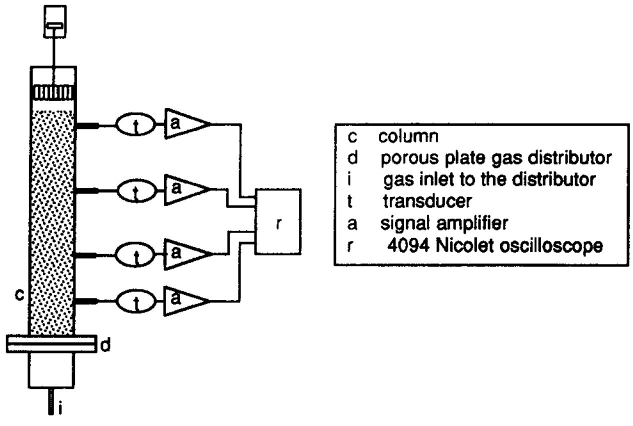

Figure 1. Experimental apparatus and pressure signal acquisition and recording system.

were used, ε_{mb} being only slightly larger than ε_{mf} in this case. Whatever the type of solids tested, the propagation velocity of the disturbances was determined as the ratio of the distance between two pressure probes to the time delay between the corresponding pressure signals.

RESULTS AND DISCUSSION

Figures 2–4 show relative pressure–time profiles recorded at different heights (z) above the gas distributor in response to piston step compressions. The dimensionless pressures are

$$p_d(z) = \frac{p_b(z)}{\frac{W_s}{A}},$$

where $p_b(z)$ are the static bed pressures relative to the atmospheric pressure and W_s/A is the ratio of the total weight of solids in the column and the column cross section area. The figures refer to solids of group A (porous silica, $d_p = 40$–$90\,\mu$m, figure 2), group B (silica sand, $d_p = 100$–$400\,\mu$m, figure 3) and group D (glass ballotini, $d_p = 800$–$1200\,\mu$m, figure 4), all fluidized at the minimum bubbling conditions.

The time delays of the onset of the disturbance at various heights above the distributor are apparent in figures 2–4. The corresponding propagation velocities (c) are 20.6 m/s for porous silica, 26.0 m/s for silica sand and 54.0 m/s for glass ballotini. The amplitude of p_d decreases when changing from finer and lighter (figure 2) to coarser and heavier solids (figure 4). This reflects the changes in the permissible depth of the piston stroke.

Propagation velocities in beds of different materials are reported in figure 5 as a function of bed voidage. Values of c for group A and B solids exhibit the same trend in the whole range of voidage. Velocities first steeply decrease at $\varepsilon > \varepsilon_{mf}$, then slowly increase to reach values of 14–20 m/s for $\varepsilon > 0.55$. Group D and B–D solids appear with single values of c in the plot of figure 5, because minimum fluidization and minimum bubbling velocities are practically the same for these materials.

Table 1. Properties of the solids used

Bed material	Symbols	d_p (μm)	ρ_p (kg/m^3)	U_{mf} (cm/s)	U_{mb} (cm/s)	ε_{mf}	ε_{mb}	t_p (s)	Geldart's group (1973)
Glass ballotini	○	40–90	2600	0.66	0.77	0.418	0.469	0.034	A
Glass ballotini[a]	◇	100–200	2600	2.1	2.6	0.387	0.406	0.181	B–A
Glass ballotini	◆	400–600	2600	20.0	20.0	0.447	0.447	2.006	B–D
Glass ballotini	△	800–1200	2600	54.0	54.0	0.445	0.445	8.024	D
Silica sand	▲	100–400	2600	4.66	6.63	0.379	0.413	0.501	B–A
FCC	■	40–90	2100	0.23	0.64	0.364	0.462	0.027	A
Porous allumina	●	40–90	1400	0.13	0.49	0.498	0.609	0.018	A
Porous silica	□	40–90	675	0.05	0.28	0.489	0.695	0.009	A

[a]Musmarra *et al.* (1992).

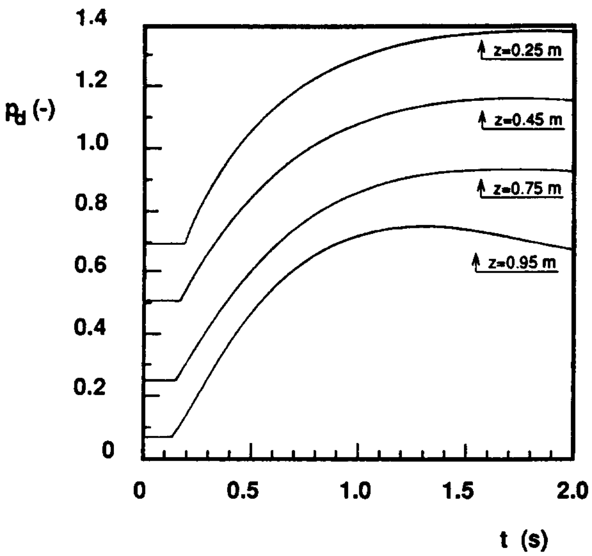

Figure 2. Dimensionless pressure–time profiles at different heights above the distributor in response to pressure step compression of the free surface of a bed of porous silica. $d_p = 40–90\,\mu$m; $\varepsilon \simeq \varepsilon_{mb}$.

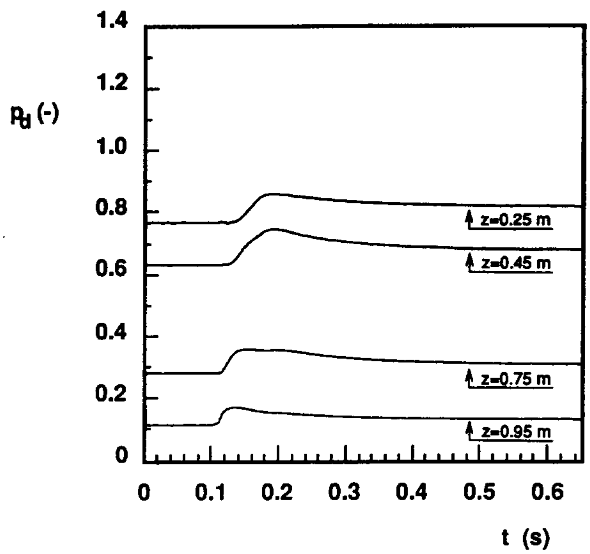

Figure 3. Dimensionless pressure–time profiles at different heights above the distributor in response to pressure step compression of the free surface of a bed of silica sand. $d_p = 100–400\,\mu$m; $\varepsilon \simeq \varepsilon_{mb}$.

Their propagation velocities are 2–4 times larger than those found for group A and B solids at the same voidages.

The effects of particle density and size on the propagation velocity are examined separately in figures 6 and 7. Figure 6 suggests that the effect of particle density on propagation can be hardly isolated from the effect indirectly exerted on bed voidage and on the width of the interval between ε_{mf} and ε_{mb} by the type of solids. Higher values of c for low density solids are found only at $\varepsilon > 0.45$. Figure 7 indicates that, for the same solids of a given particle density, c decreases as particle size decreases. But again this trend is biased by the trend of bed voidage to increase with the reduction of particle size.

The predictions of the pseudo-homogeneous model of a gas–solid mixture (Wood 1941; Wallis 1969; Roy *et al.* 1990; Musmarra *et al.* 1992) are compared to the measured propagation velocities

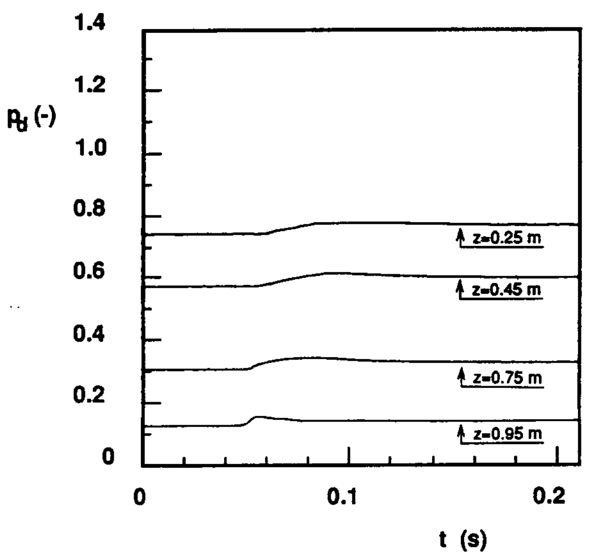

Figure 4. Dimensionless pressure–time profiles at different heights above the distributor in response to pressure step compression of the free surface of a bed of glass ballotini. $d_p = 800–1200\,\mu$m; $\varepsilon \simeq \varepsilon_{mb}$.

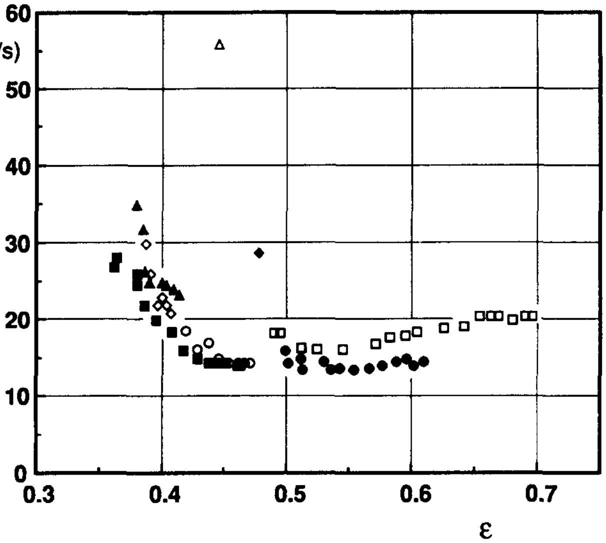

Figure 5. Propagation velocities of pressure disturbances in various beds as a function of the bed voidage. Key to symbols in table 1; ◇, Musmarra *et al.* (1992).

of pressure disturbances in figures 6 and 7. The model considers that gas and solids move in phase, an assumption that is more likely to hold for the shorter response time of the particle to gas flow $t_p = \rho_p d_p^2/18\mu$, where μ is the gas viscosity (Kürten *et al.* 1966).

According to the pseudo-homogeneous model:

$$c = \sqrt{\frac{E_{eff}}{\rho_m}} \qquad [1]$$

where $E_{eff} = p_a/\varepsilon$ is the effective elasticity modulus and $\rho_m = \rho_p(1-\varepsilon)$ is the density of the gas–solid mixture. Absolute pressure p_a, particle density ρ_p and bed voidage ε are involved in this equation.

The trends of calculated and experimental curves are similar but the actual agreement between values of c obtained from [1] and data points becomes increasingly poor for decreasing bed voidage. In particular, the experimental rise at voidages below 0.45 contrasts with the weak variations of

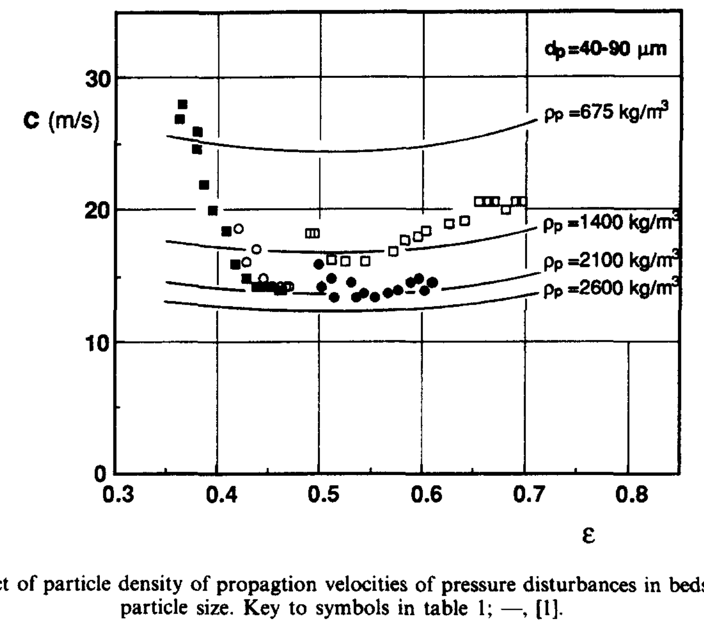

Figure 6. Effect of particle density of propagtion velocities of pressure disturbances in beds of constant particle size. Key to symbols in table 1; —, [1].

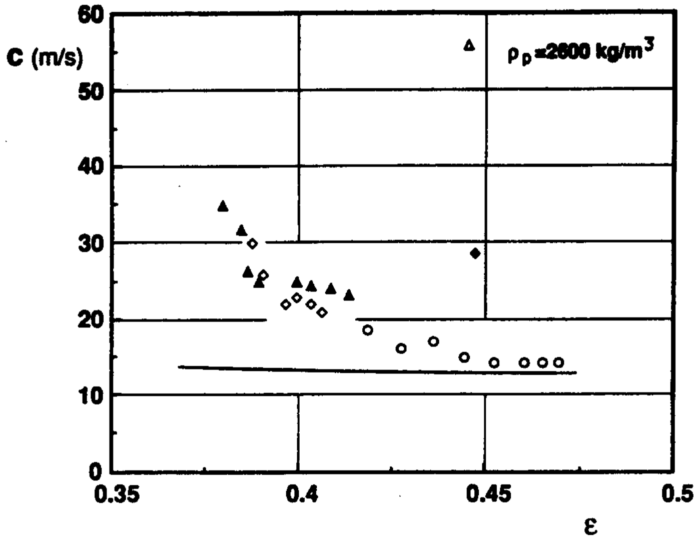

Figure 7. Effect of particle diameter on progation velocities of pressure disturbances in beds of constant particle density. Key to symbols in table 1; —, [1]; ◇, Musmarra *et al.* (1992).

c expected from the model. The possible contribution of an elastic component of interparticle collision to the elasticity modulus E_{eff}, ignored by the model, might be responsible for this effect. Figure 6 further shows that the influence of solid density on c is not properly taken in account. Values of c are overestimated for low density, and underestimated for high density particles. The dependence of c on particle diameter is not envisaged by [1]. This might explain the closer agreement between theory and experiment for group A and B than for group D and B–D solids in figure 7. It is not surprising that larger discrepancies are exhibited by group D and B–D solids, which are less amenable to the pseudo-homogeneous model because of the longer particle response time.

CONCLUSIONS

Propagation velocities of pressure disturbances can be determined conveniently in a bubble-free fluidized bed by impulsive step compression of the bed free surface.

The pseudo-homogeneous model provides a first approximation approach to the evaluation of propagation velocities of pressure disturbances in bubble-free fluidized beds of solids of different properties. Close to the bed minimum bubbling velocity, group A and B solids conform to the model predictions with regard to the effect of particle density on the propagation velocity. On the contrary, close to the bed minimum fluidization velocities, considerable discrepancies are found between calculated and measured velocities. The largest discrepancies are shown by group D and B–D solids, whose minimum fluidization and minimum bubbling velocities are almost concident. This suggests that particle size and density affect the propagation velocity of pressure disturbances indirectly, via variations of bed voidage and of the width of the voidage interval between minimum fluidization and minimum bubbling velocity.

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