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LETTER TO THE EDITOR

COMMENTS ON "PROPAGATION CHARACTERISTICS OF PRESSURE DISTURBANCES ORIGINATED BY GAS JETS IN FLUIDIZED BEDS"†

In a recent study, Musmarra *et al.* (1992) presented further evidence as to the smaller magnitude of the velocity of sound in fluidized beds by considering various types of disturbances. The wave velocities determined were found to be in the range 6–30 m/s for disturbances ranging from gas jetting and the injection of single bubbles and bubble chains to the compression of the bed surface. Earlier, Grek & Kisel'nikov (1964) reported a value of 4 m/s based on acoustic measurements, while recently Roy *et al.* (1990) obtained a value of 9 m/s based on the cross-correlation of pressure fluctuations downstream of the disturbance, the same as the one used by Musmarra *et al.* (1992). Even though these are in agreement with each other with regard to the order of magnitude of the velocity of sound in fluidized beds, one needs to exercise caution when ascertaining the actual magnitudes, considering the difficulties in identifying and establishing the direction as well as the velocity of propagation, a fact also stressed by Musmarra *et al.* (1992). However, this is best illustrated by considering the uncertainties involved with regard to the interpretation of radial propagation of the disturbance from the centre of the bed towards the wall, and analysing the measurements of Musmarra *et al.* (1992).

Musmarra *et al.* (1992) obtained a propagation velocity of 8.6 m/s in the radial direction for the disturbances caused by gas jetting at the centre of the distributor. In particular, the cross-correlation between pressure signals from a probe at the centre (0.06 m from the distributor) and another at the wall (0.35 m i.d. bed) due to the above disturbances yielded a positive time delay of 0.022 s. The main essence of this communication is to show that a "pseudo-wave velocity" of 8.6 m/s can also be predicted for the configuration employed by Musmarra *et al.* (1992), by considering the pressure field around a Davidson & Harrison (1963) fluidization bubble.

Since the nature of the disturbance responsible for the pressure fluctuations reported in figure 4 of Musmarra *et al.* (1992) (jet velocity = 35 m/s, superficial gas velocity = 0.026 m and static bed height = 0.3 m with the probe tip 0.06 m from distributor) is not completely known, let us arbitrarily consider a bubble diameter of 0.06 m travelling up from −0.15 to +0.15 m, i.e. a total distance of 0.3 m. From the Davidson & Harrison (1963) model, the excess pressure distribution around a bubble in relation to that at a point remote from the bubble can be written in polar coordinates (r, θ) as

$$\begin{aligned} \Delta P_e &= \rho_b g R\left(\frac{R^2}{r^2}\right)\cos\theta \quad r > R \\ &= \rho_b g R\left(\frac{r}{R}\right)\cos\theta \quad r \leqslant R, \end{aligned} \qquad [1]$$

where ρ_b is the bulk bed density and R is the bubble radius of curvature. Equation [1] predicts that the maximum in the pressure fluctuation due to a bubble passage occurs when the bubble nose (or boundary) touches the pressure sensor, as long as the eccentricity between the axis of symmetry of the bubble and the pressure sensor does not exceed $\sqrt{2/3}R$. When the eccentricity exceeds this value, the maximum in the pressure fluctuation always occurs ahead of the bubble boundary, i.e. even before the bubble boundary touches the probe. In view of this, it is very important to take this inevitable time delay into account in estimating the propagation wave velocity by cross-correlating the pressure fluctuations between the static pressure sensors at the bed centre and the one

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at the wall. For the bed size employed by Musmarra *et al.* (1992), i.e. for a sensor gap of 0.175 m in the radial direction, this is shown schematically in figure 1, wherein the maximum in the pressure fluctuation recorded at the wall tap does not exhibit a sharp maximum unlike that for the probe at the bed centre. The simulated pressure fluctuations in time coordinates obtained from [1], along with

$$-0.15 \leqslant r \cos \theta \leqslant 0.15 \quad [2]$$

$$U_{\mathrm{br}} = 0.71\sqrt{gD_{\mathrm{b}}} \quad [3]$$

and

$$r \cos \theta = U_{\mathrm{br}} t, \quad [4]$$

are cross-correlated and the resultant cross-correlation function is presented in figure 2. The probable time delay, clearly evident from figure 2, is 0.020196 s, which when coupled with a sensor spacing (bed centre and the wall) of 0.175 m results in a "pseudo-wave velocity" of 8.6 m/s, in exact agreement with the value reported in figure 5 of Musmarra *et al.* (1992). Only a portion of the cross-correlation function is shown here to indicate the maximum, i.e. the probable time delay between the two pressure traces. The cross-correlation function (not shown in figure 2) reaches the first minimum at a time delay of 0.29376 s with a coefficient of −0.870620. These values are not relevant for comparison with the minima in the cross-correlation function reported in figure 5 of Musmarra *et al.* (1992), since in the present case a bubble rise velocity of 0.545 m/s is used compared to the jet velocity of 35 m/s in figure 4 of Musmarra *et al.* (1992). Also, the magnitude of the pressure fluctuation inferred from the simulated records (maximum to minimum) for the bed centre probe amounts to 900 Pa, while that for the wall probe corresponds to 10 Pa.

A further analysis reveals that the time delay between the pressure fluctuation records from the two radial locations (i.e. the bed centre and wall) varies with the analysis time length of the pressure fluctuation records, thus predicting a "pseudo-wave velocity" in the range 5–20 m/s for different analysis time lengths. This, in conjunction with the above coincidence between the measured value reported by Musmarra *et al.* (1992) and the expected value of 8.6 m/s, raises two important

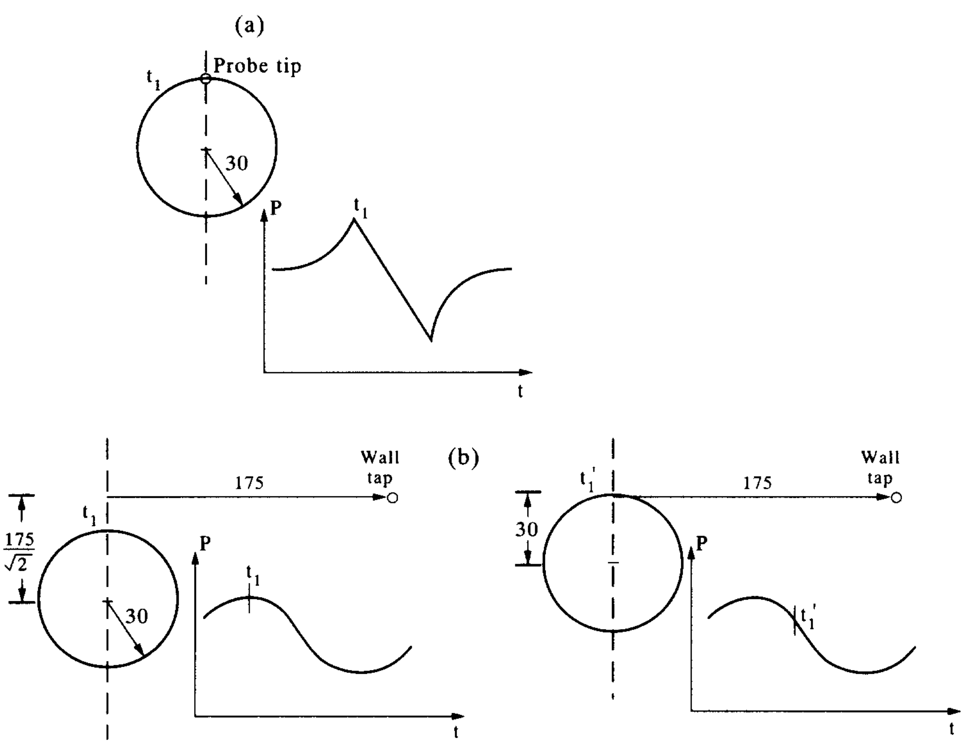

Figure 1. A schematic diagram of the bubble-to-probe hit with the resultant pressure change pattern, showing the location of the maximum in the pressure fluctuation record for a probe at (a) the bed centre and (b) the wall tap.

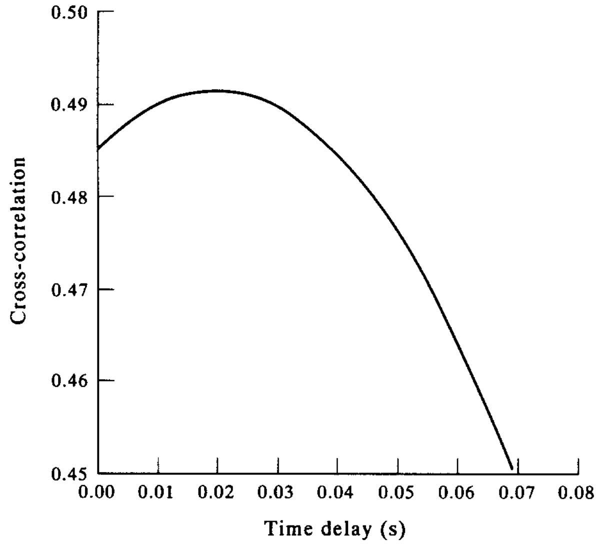

Figure 2. Cross-correlation function of the simulated local pressure fluctuations from the axial and wall probes, separated by 0.175 m, shown in figure 1, indicating a peak time delay of 0.020196 s.

questions. The first is whether the assumption that the disturbance will be transmitted very rapidly to both the locations at the bed centre and the wall if the suspension were to be truly liquid like is justifiable. This appraisal is necessary since a void in a fluidized bed will be surrounded by a characteristic pressure field and, depending on the nature of this, in certain cases, time delays corresponding to velocities in excess of the bubble rise velocity might result from a cross-correlation of the respective pressure fluctuation records.

The second question relates to the uncertainties in establishing and identifying the source of the detected disturbance at a location far from the source of disturbance. This is essential to fix the path and hence the directionality of the wave propagation. For example, the pressure fluctuation recorded at a point will be influenced by both local and global variations, and this needs to be taken into account in establishing the wave velocity. This is only possible with simultaneous measurements from an array of sensors dispersed in the region between the source and the detection regions. Acoustic measurements, such as the one reported by Grek & Kisel'nikov (1964), might be helpful in cross-checking the magnitudes obtained from the cross-correlation of pressure fluctuations in this regard. Moreover, a knowledge of the expected pressure fluctuations due to a distant disturbance or for the existing bubble spatial configuration is a prerequisite either for establishing the propagation wave velocity beyond doubt or for explaining some strange features such as the increase in the amplitude of the disturbance downstream of the source of disturbance, observed by Musmarra *et al.* (1992).

REFERENCES

DAVIDSON, J. F. & HARRISON, D. 1963 *Fluidized Particles*. Cambridge Univ. Press, Cambs.

GREK, F. Z. & KISSEL'NIKOV, V. N. 1964 Determining the void fraction of fluidized systems by an acoustic method. *Int. Chem. Engng* **4**, 263–269.

MUSMARRA, D., VACCARO, S., FILLA, M. & MASSIMILLA, L. 1992 Propagation characteristics of pressure disturbances originated by gas jets in fluidized beds. *Int. J. Multiphase Flow* **18**, 965–976.

ROY, R., DAVIDSON, J. F. & TUPONOGOV, V. G. 1990 The velocity of sound in fluidized beds. *Chem. Engng Sci.* **45**, 3233–3245.

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