Detection Of Lateral Non-Uniformities In Fluidized Bed Combustors

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ABSTRACT

This paper addresses the detection of lateral non-Uniformities in fluidized bed combustors by a novel probe technique not reported so far , by using the horizontal differential pressure fluctuations associated with bubble flow. The salient features of these fluctuations are highlighted utilizing the simulated records obtained by considering the Davidson's pressure field around a bubble. The simulation approach is validated by a comparison with the measured vertical and horizontal differential fluctuations in a freely bubbling fluidized bed.

INTRODUCTION

The concept of 'fluidization' finds wide application in combustors and incinerators,and ,from an environmental view point they find wide acceptance. At present they are being pursued vigorously to handle a wide array of fuels including municipal solid waste.

The onset of bubbling in a fluidized bed followed by continuous growth and subsequent eruption at the bed surface, greatly influences solid circulation patterns and gas phase mixing which inturn affects various in-bed processes like heat and mass transfer, erosion of in-bed surfaces, attrition and elutriation. In addition the mobility of a fluidized bed is also affected by distribution of bubbles across the bed cross-section, for the presence of any lateral non-uniformities in bubbling can severely affect the yield of a reactor or a combustor. These non-uniformities can arise on account of uneven distribution of the fluid or partial blockage of distributor plate including the disposition of various internals present in the combustor. It is always desirable to monitor the development of such non-unifomities in the course of operation of large units.

There are various techniques[1] that have been developed for the determination of local bubble characteristics but most of them are limited either to a small depth of observation or are impractical in large beds or hot and corrosive environments of industrial fluidized beds or combustors.[2] Of late, the interpretation of differential pressure fluctuations in terms of fluidization parameters is receiving considerable attention because of its potential application in demanding environments. Some of the advantageous features of this technique include the inherent robustness of such probes, their amenability for cooling in high temperature applications, the enormous amount of information contained in the response of such probes[3], their relative insensitivity to mechanical damage or fouling, the possibility of locating them even outside the system.[4]

Any probe system meant to detect lateral non-uniformities must be able to reveal the presence of bubbles on both sides of its location using as minimum a number of sensors as possible. In this context the present study focusses on the development of a novel probe technique utilizing horizontal pressure differential record which is highly sensitive to the directionality of bubble approach (i.e) from left or right, and, which so far has not been reported.[5] Specifically this paper addresses the prediction and simulation of horizontal differential pressure fluctuations under the freely bubbling conditions. The effect of growth of bubbles and the presence of other bubbles are considered along with the randomness of the bubble traversing path by considering the pressure field around a Davidson's bubble.[6] The resulting trends are discussed in relation to those obtained experimentally from a freely bubbling 2-D bed.

SIMULATION OF HORIZONTAL DIFFERENTIAL PRESSURE FLUCTUATIONS

Figure 1 shows a schematic of a typical bubble flow sequence past the horizontal differential pressure probe and the resultant response. Since it is difficult to quantify the pressure distribution around a bubble with wake in terms of an usable model, circular bubbles are considered here. It will be shown later that even with this approach the predicted patterns resemble very closely with the measured records taken under freely bubbling conditions.

Considering the pressure field around a Davidson's bubble[6] the excess pressure distribution relative to that in the dense phase remote from the bubble can be written as

$$\Delta P_e = \Delta P_s[r/S]\cos\Theta \qquad r \le R \qquad (1)$$

$$= \Delta P_s[R^3/Sr^2]\cos\Theta \qquad r > R \qquad (2)$$

where

$$\Delta P_s = (\rho_s - \rho_f)(1 - \epsilon_{mf})\, g\, S$$

The normalized pressure gradient recorded by the horizontal differential pressure probe can be related as

$$[\Delta P_e / \Delta P_s] = [\Delta P_e / \Delta P_s]_{right} - [\Delta P_e / \Delta P_s]_{left} \qquad (3)$$

(either of the two can be taken as reference) and the variations of this for a random bubble trajectory depicted in Fig.2 can be predicted in time co-ordinates by

$$Y = U_y t \qquad (4)$$

$$U_{br} = 2/3 \sqrt{g R} \qquad (5)$$

$$\mathrm{Tan}\beta = U_x/U_y \qquad (6)$$

$$r = \sqrt{E^2 + Y^2} \qquad (7)$$

and $$E = e - Y\,\mathrm{Tan}\beta \qquad (8)$$

The effect of bubble growth is simulated by assuming

$$D = D_i + Y^{1.64} \qquad (9)$$

to account for a high rate of growth to study the effect of rapid growth on the simulated differential pressure change patterns (This extreme limit corresponds to a growth in size of 60mm across a bed height of 180mm as found in actual measurements[7]). The presence of an another bubble on the pressure change recorded at the probe tip is considered by a summation of the pressure field due to each one when the other is absent and vice versa. This approach is found to be able to predict the pressure patterns satisfactorily under vigorously bubbling conditions as also verified by high speed photography.[8]

The effect of bubble interactions on the velocity of individual bubbles is taken through Clift and Grace model[9], where for bubbles in vertical alignment.

$$U_1 = U_{b\infty 1} + U_2 R_2^3 / (x_d + R_1)^3 \qquad (10)$$

$$U_2 = U_{b\infty 2} + U_1 R_1^3 / (x_d - R_2)^3 \qquad x_d \geq R_1 + R_2$$

$$= U_1 + U_{b\infty 2} \qquad x_d < R_1 + R_2 \qquad (11)$$

EXPERIMENTAL

To compare the simulated horizontal pressure differential fluctuations under freely bubbling conditions, measured records [8] obtained using wall pressure taps on a two-dimensional bed (0.4m x 0.028m) with sand in the size range of 360μm to 550μm are used here. The excess gas velocity range is from 0.03 to 0.23 m/s. Two pressure transducers (HBM PD 0.1, SCANIVALVE 5PSID) coupled to carrier frequency amplifiers (HBM KTS-5) and connected to a microprocessor based signal analyzer (SM 2100B IWATSU) complete the instrumentation setup. The size of the pressure taps is 0.8mm I.D and they are arranged to record simultaneously vertical and horizontal pressure gradients and the adequacy of the time constant verified by changing the data sampling time interval. The data collected correspond to a transducer interrogation frequency of 409 HZ.

RESULTS & DISCUSSION

Effect of bubble growth and obliquity

The effect of bubble growth on the resultant horizontal pressure fluctuation is presented in Fig.3. For a vertically rising bubble, as is the case here, there is a transition from negative to positive gradients followed in between by a dwell period during which the gradient is zero. This dwell period actually represents the time interval during which both the sensors of the probe are engulfed by the bubble. The sensitivity of the probe response to the directionality of the bubble approach (i.e.) from left or right is amply clear by the fact that in the second case the transition is from positive to negative gradient, during the period of bubble to probe interaction. If the bubble starts growing considerably during its ascent and past the probe, its net affect is to alter the time scales involved rather than the nature of fluctuation.

Fig.4(a). depicts the effect of bubble growth for an oblique bubble to probe hit wherein the pressure gradients are always negative for a bubble approaching from left. Again the effect of bubble growth is only to alter the time scales associated with the bubble residence at the probe. For a bubble approaching the probe from right side, the resultant pressure gradients turn out to be always positive, as indicated in Fig. 4(b) for the case with bubble growth. This in conjunction with Fig.3 brings out the extra - ordinary sensitivity of a horizontal pressure gradient record to the directionality and obliquity of the bubble traverse. The deviation from this trend observed for the one without growth corresponds to a case where the bubble while crossing the probe obliquely does not completely engulf the two sensors of the probe. This can be easily understood by referring to Fig.2 where in

$$L1 = (e+S) \cos\beta > R \quad (12)$$

and

$$L2 = e \cos\beta < R \quad (13)$$

Only when both L1 and L2 are less than R , the gradients would be either entirely positive like in Fig.4(b) or entirely negative as in Fig.4(a). However the obliquity can be easily discerned from the fact that there is an additional incursion from negative to positive as denoted by the region 'abc' which however is not going to be there for a vertically rising bubble.

Effect of the presence of other bubbles

A comparison of the simulated vertical and horizontal pressure gradient fluctuations for successive bubble flow sequence past the probe is given in Fig .5. This simultaneous comparison of both vertical and horizontal gradients will be used to validate the soundness and utility of the simulation approach by a comparison with experimental records for the same probe configuration.

Figure 5 shows that for an oblique traversing path horizontal gradients are positive as expected and discussed earlier. The vertical pressure gradients are well known and discussed elsewhere.[10] The important point to note here is that when the peak in vertical gradient is lower , the peak in horizontal gradient would be higher and vice versa , as can be seen at time intervals A-a and B-b. In the simulation the bubble interaction is suitably taken into account.

Comparison with experimental records

An experimental record of vertical and horizontal pressure differential changes simultaneously taken is presented in Fig .6. along with the probe configuration. For all the three bubbles marked by vertical gradient pulses A,B and C it can be clearly observed that when vertical gradient peak is larger , the horizontal gradient peak is lower and vice versa. The fact that the horizontal differentials are always positive tends to indicate that it is for an oblique hit with the bubble completely engulfing both the sensors of the probe on its way past the probe. The bubble approach path which can be inferred is from left of the probe. For this path and probes, the direct similarity confirms the simulated patterns are the ones resembling closely with those to be expected in freely bubbling beds.

The effect of closely spaced bubbles on the simulated gradients in both directions is noted in Fig.7. It reveals that for close spacing, the gradients at the nose of the following (trailing) bubble will be higher. The flow path is such that the trailing bubble completely engulfs the probe while the leading bubble tends to avoid one sensor of the horizontal differential probe. The sort of deviation observed here is already discussed in the context of Fig 4(b).

Figure 8 depicts the experimental recordings for close spaced bubbles in a freely bubbling bed. A comparison with the vertical gradient pulse marked D brings in the strong similarity for bubbles in the process of coalescence. The gradient at the nose of the trailing bubble is greater for both the gradients. The only difference between Fig.7 and Fig.8 is that the size of the leading bubble is smaller for simulated records whereas it is larger for experimental case. Similarly the pulses marked A,B,C and E are for bubbles at various stages of coalescence.

Sensitivity of horizontal differential probe response

Figure 9 tends show the various utility of horizontal differential trace in the sense that it contains much more information than that contained in a vertical gradient record. For the vertical probe(sensor spacing = 6mm as that for horizontal) the flow path corresponds to a bubble flowing obliquely but roughly midway through the two sensors. The resultant gradient is almost symmetric but the point to be noted here is that, it can't reveal whether the bubble approached from right or left since in both cases the pattern would be same. However, the horizontal gradient while revealing that the bubble completely intercepted the probe while rising obliquely(as the gradients are either completely negative or completely positive) in addition gives the information that it approached from right side of the probe. For a bubble flowing exactly midway through the two sensors of the probe the two peaks in the horizontal gradient pulse will be equal to each other.

It is this feature which facilitates the detection of lateral non-uniformities by requiring the presence of bubbles on both sides of the probe for uniformity in bubbling. The salient features of the horizontal pressure gradient fluctuations could be incorporated in a bubble detection and fluidization quality monitoring program for on line detection of lateral non-uniformities.

Unambiguous bubble detection

By a suitable positioning of the sensors of the probe and taking advantage of the sensitivity of the horizontal gradients to bubble flowpath , it is possible to detect the bubble rather unambiguously. For example, Fig.10 considers a probe system employed by Dent etal[11] in a Fludized bed combustor. For a vertically rising bubble midway through the two sensors, the horizontal differential is zero and this feature can be used directly measure the bubble diameter in conjunction with the vertical gradient information for this probe configuration. For a bubble flowing eccentrically but vertically past the probe, the horizontal differential resembles that of a point pressure fluctuation when it avoids one or both the sensors of the probe.

CONCLUSION

Lateral non-Uniformities in fluidized bed combustors can be detected with the help of horizontal differential pressure fluctuations with least number of sensors. A single horizontal differential probe can be used to judge whether or not bubbling is there on both sides of the probe by incorporating the unique sensitivity of this probe response to bubble traversing path in a detection program.Whether the bubble approached from left or right side of the probe can be easily detected since there is a complete transition from one type of pattern to other which are easily distinguishable and can be taken into account. In addition it is also possible to generate more information regarding bubble properties, which is rather authentic and unambiguous.

The technique can be applied in a commercial unit either by making the horizontal differential pressure probes as part of the bed internals or by locating them just on the walls of the combustor. Detection of the presence of lateral non -Uniformities will lead to corrective actions and hencewith a better degree of uniformity, the average bubble size can be reduced. This will help in a lower level of elutriation from the top of the bed surface.

REFERENCES

1. N.P.Cheremisinoff, " Review of experimental methods for studying the hydrodynamics of gas-solid fluidized beds", Ind. Eng. Chem. Process. Des. Dev., 25:329(1986).

2. O.Sitnai, " Utilization of pressure gradient records in fluidized beds with internals for bubble parameter determination", Chem.Eng.Sci, 37:1059 (1982).

3. C.M.Atkinson and N.N.Clark, " Gas sampling from fluidized beds - A novel probe system", Powder Technol., 54:59(1988).

4. Ghadiri,M., B.Carter, R.R.Rathbone, R.Clift et al., " Diagnosis of gas flow patterns in fluidized beds", in proceedings of the 4th International Fluidized bed Conference, London, Institute of Energy, 1988, pp I/3/1-16.

5. A.Venkata Ramayya, S.P.Venkateshan and A.K.Kolar, " Bubble detection with horizontal pressure gradient measurements in gas-fluidized beds", submitted for publication.

6. J.F.Davidson, " Symposium on fluidization-Contribution to discussion ", Trans .Inst. Chem. Engrs 39:230 (1961).

7. A.V.Ramayya, S.P.Venkateshan and A.K.Kolar, " Large particle fluidization studies with a differential pressure fluctuation record " in proceedings of the 12th International Conference on Fluidized Bed Combustion, vol.2 ,1993, p 877-883.

8. A.Venkata Ramayya, Ph.D Dissertation, Indian Institute of Technology, Madras, India, 1991.

9. R.Clift and J.R.Grace, Fluidization; J.F.Davidson, R.Clift and D.Harrison, Eds. Academic press, London, 1985, pp.73-132.

10. A. Venkata Ramayya, S.P.Venkateshan and A.K.Kolar, " Estimation of bubble parameters from differential pressure measurements in fluidized beds", Powder Technol., 87:113(1996).

11. D.Dent, R.D.LaNauze, T.Joyce, V.Fulford and P.Peeler, " Differential pressure measurements - Their application to measurement of fluidized bed Combustion parameters" , in proceedings of the 10th International Conference on Fluidized Bed Combustion, vol.1, 1989, p.451.

NOMENCLATURE

D_p	Particle diameter,m
E	Eccentricity of bubble centre from the sensor,m
e	Eccentricity at the instant bubble nose crossing the probe,m
H_s	Static bed height,m
R	Bubble radius,m
r	Distance between bubble centre and the point of interest,m
S	Sensor spacing of the probe,m
t	Time,s
U	Superficial gas velocity,m/s
U_{br}	Bubble rise velocity ,m/s
$U_{b\infty}$	Bubble rise velocity in isolation,m/s
X_d	Vertical distance between two bubble centres,m
Y	Vertical distance between bubble centre and plane of the probe,m
Z	Vertical distance from distributor plate,m
β	Obliquity of bubble centre with probe,degree
Θ	Angle subtended by the line joining the bubble centre and the sensor at a particular instant,degree
$\in$	Voidage
ρ	Density,Kg/m^3

Subscripts

f	Gas
s	Solid
mf	Minimum fluidization
1	Leading bubble
2	Trailing bubble
X	X Component
Y	Y Component

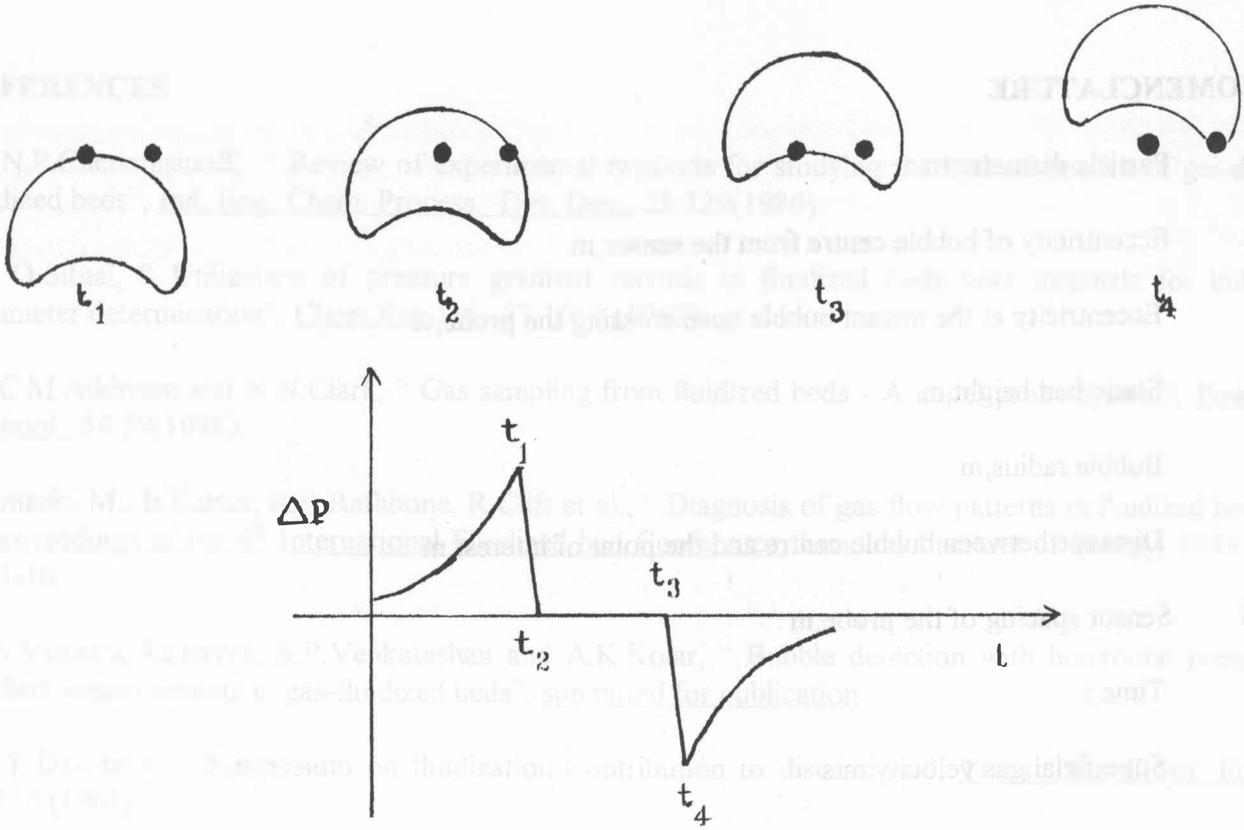


Fig: 1 A typical bubble to probe encounter and the resultant response.

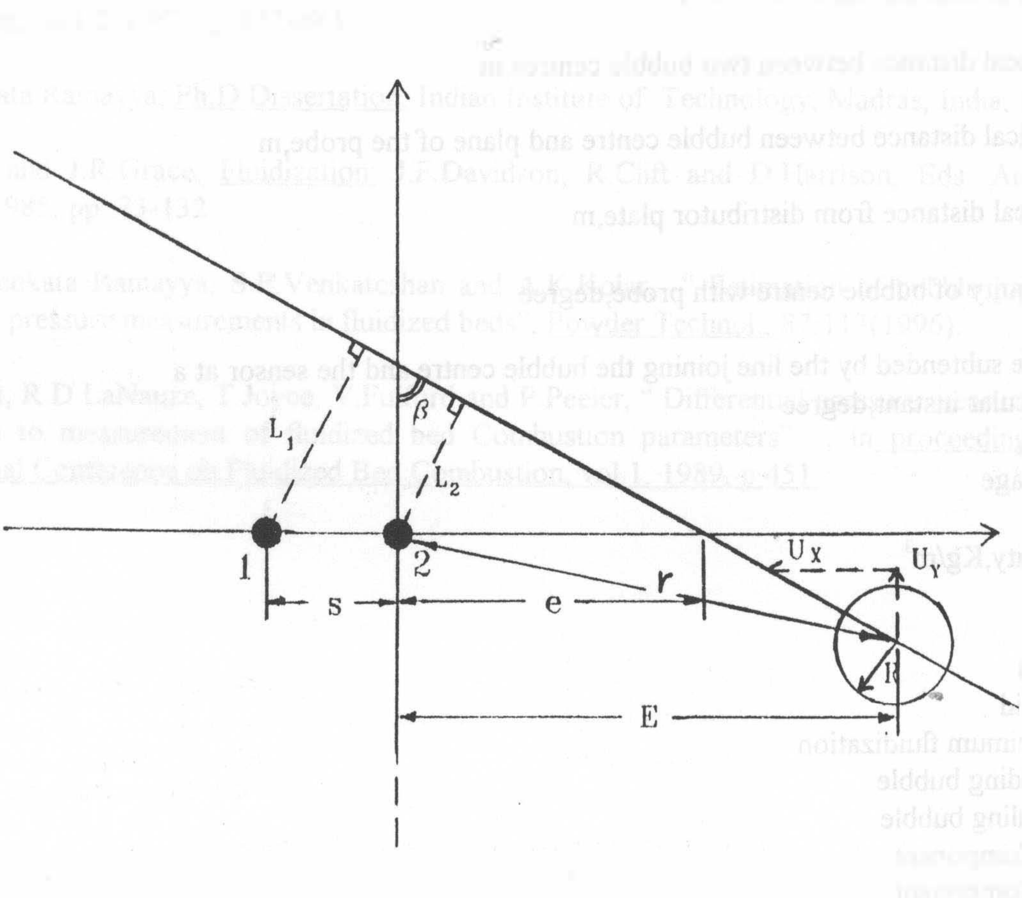


Fig.2 A typical random bubble trajectory.

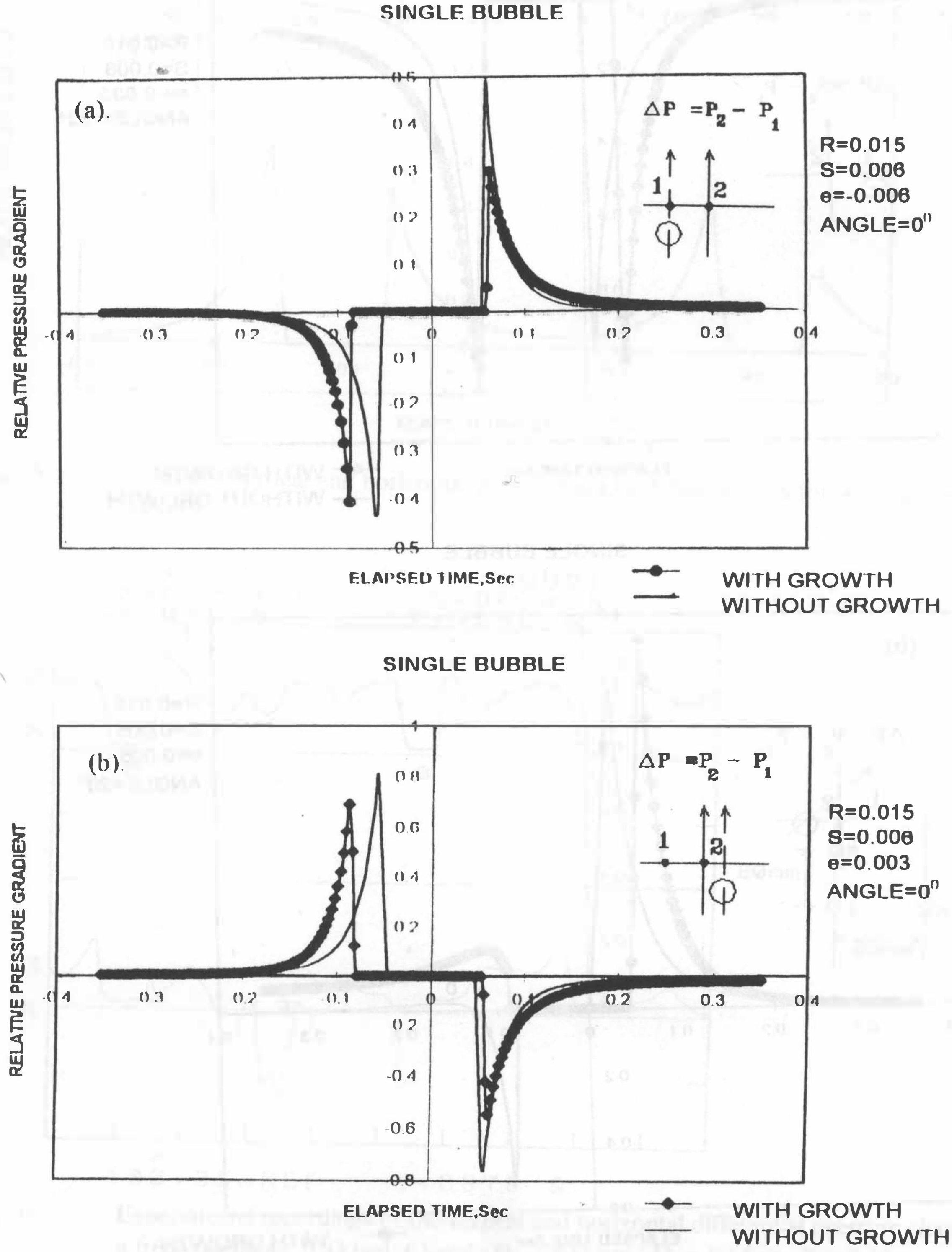


Fig . 3 : The effect of bubble growth on the horizontal pressure gradient record for a vertically rising bubble.

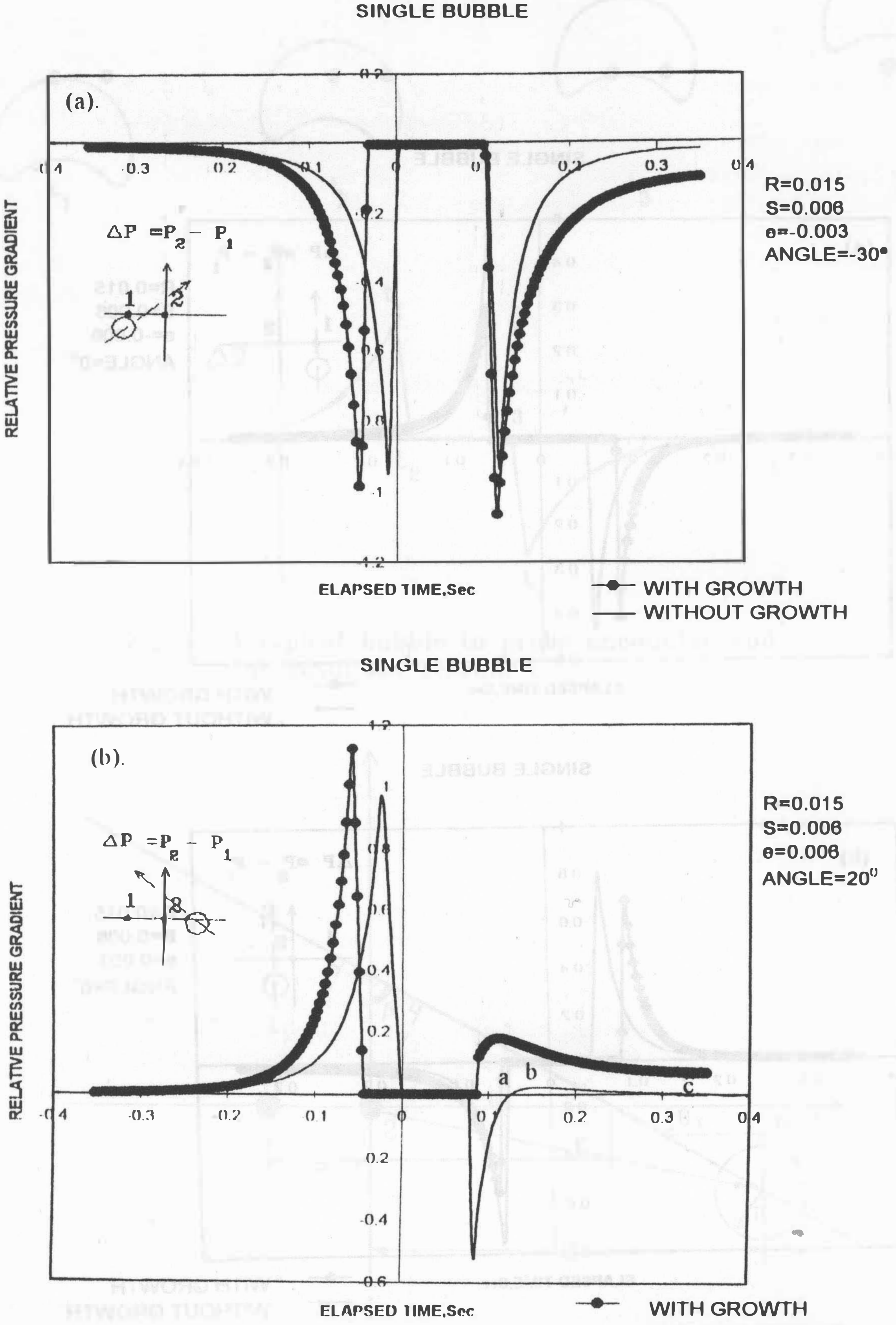


Fig. 4 The effect of obliquity and bubble growth on horizontal pressure gradient fluctuation.

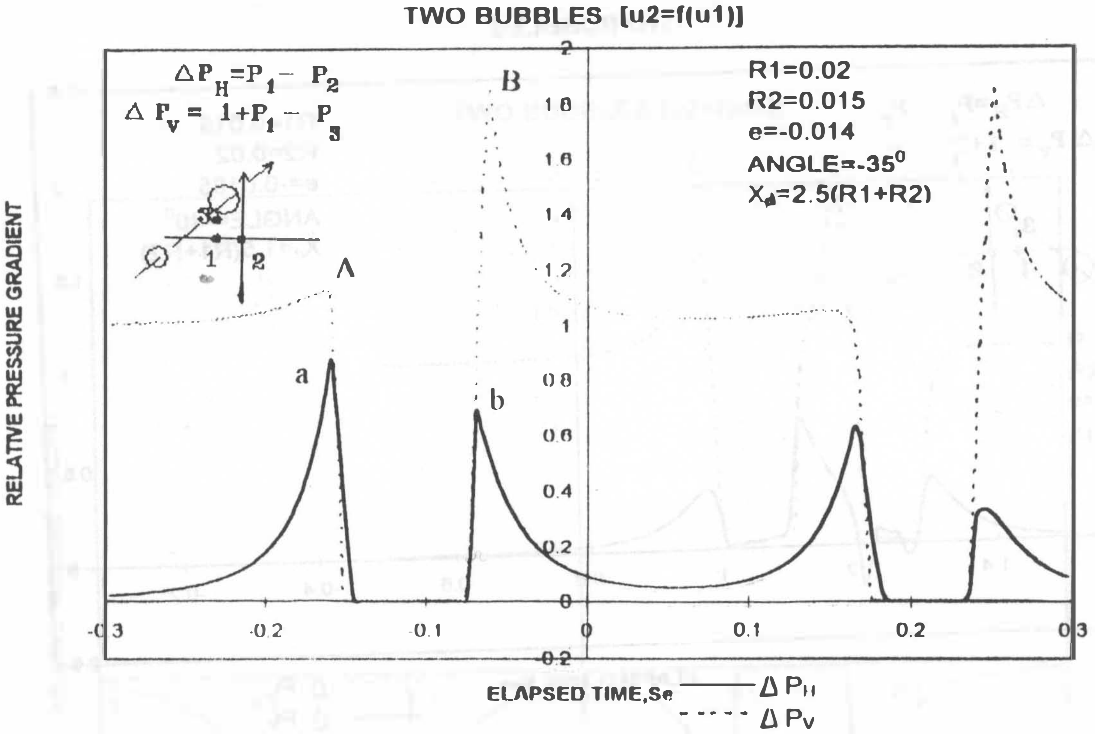


Fig. 5 Simulated vertical and horizontal pressure gradient fluctuations for wide spaced bubbles

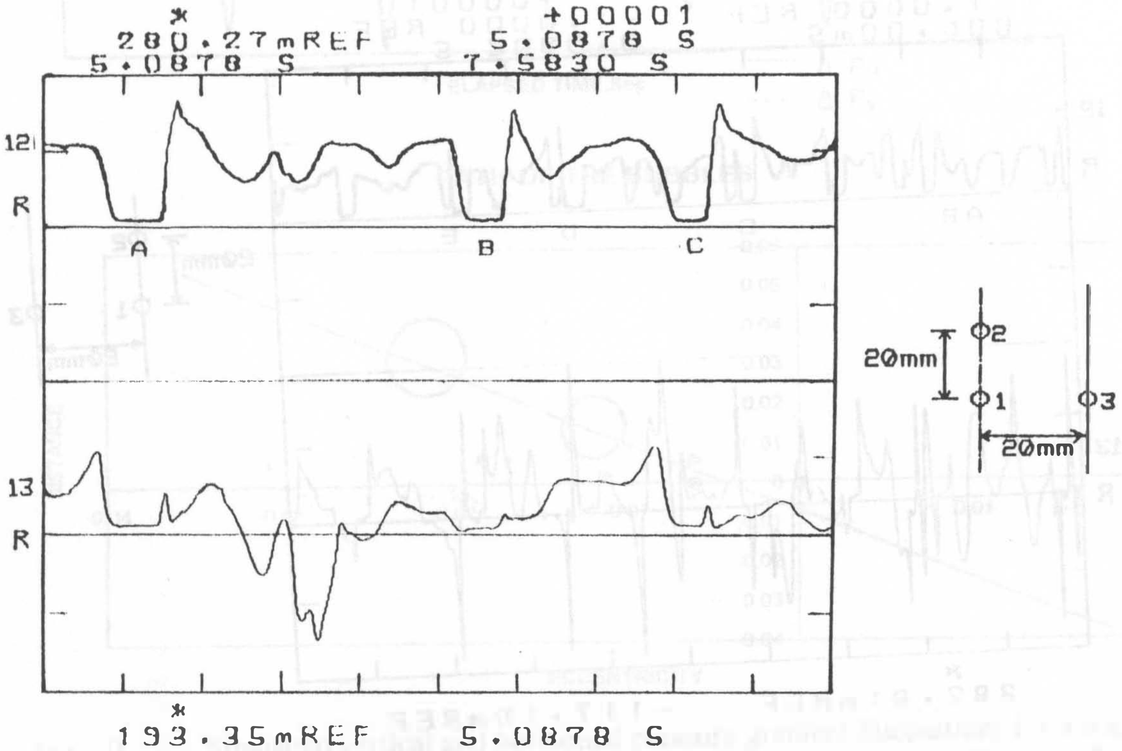


Fig. 6 Experimental recordings of the vertical and horizontal differential pressure changes in a freely bubbling 2-D bed (Sand , D_p = 402 μm , H_s = 0.55 m , Z = 0.32 m , $U-U_{mf}$ = 0.15 m/s) from 5.0878 s to 7.5830 s. At 5.0878 s , the vertical pressure differential is 280.27 mREF while that of horizontal pressure differential is 193.35 mREF .

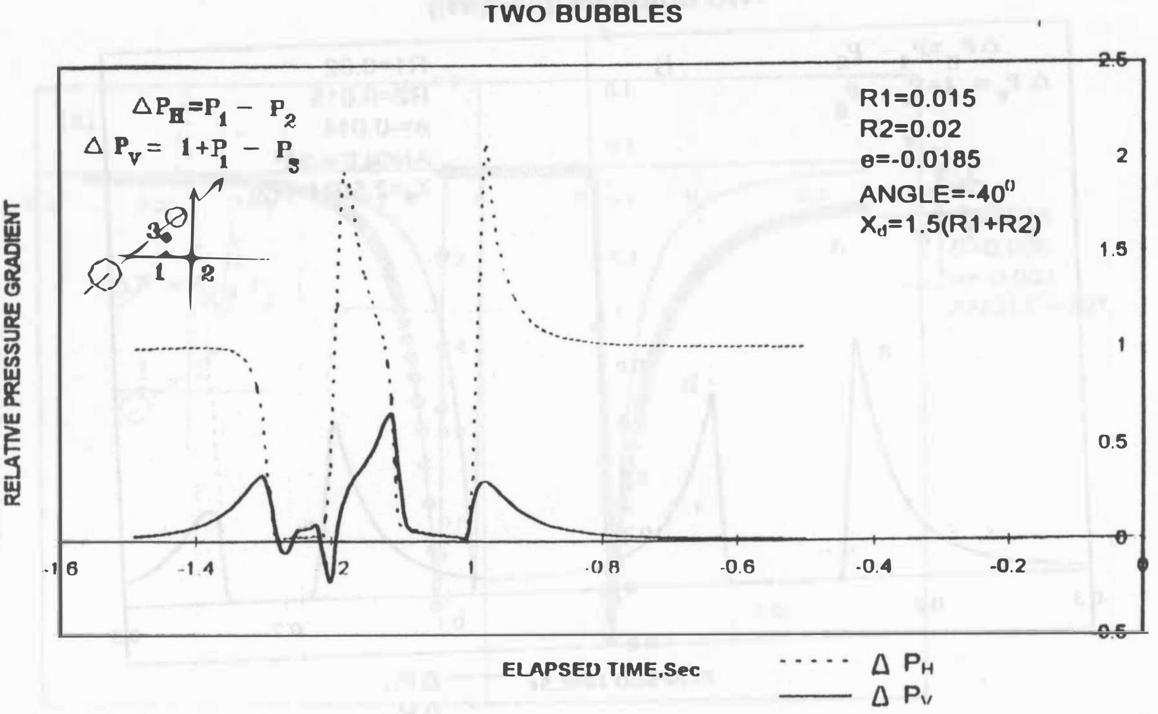


Fig . 7 Simulated vertical and horizontal pressure gradients for close spaced bubbles.

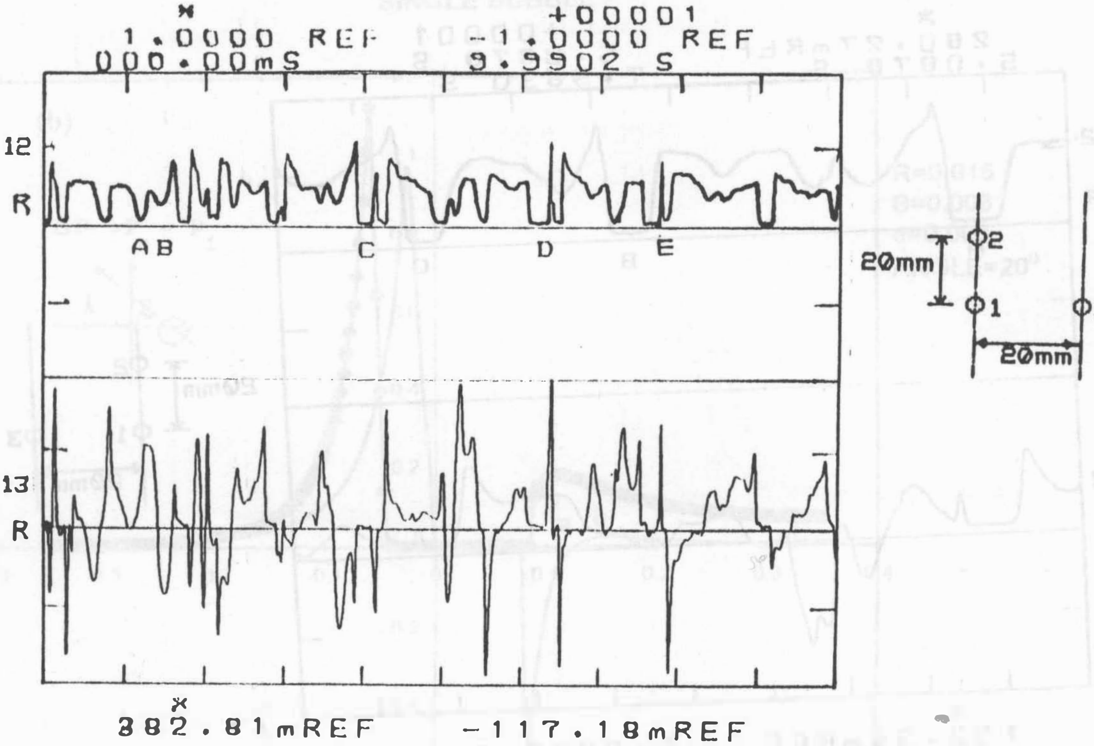
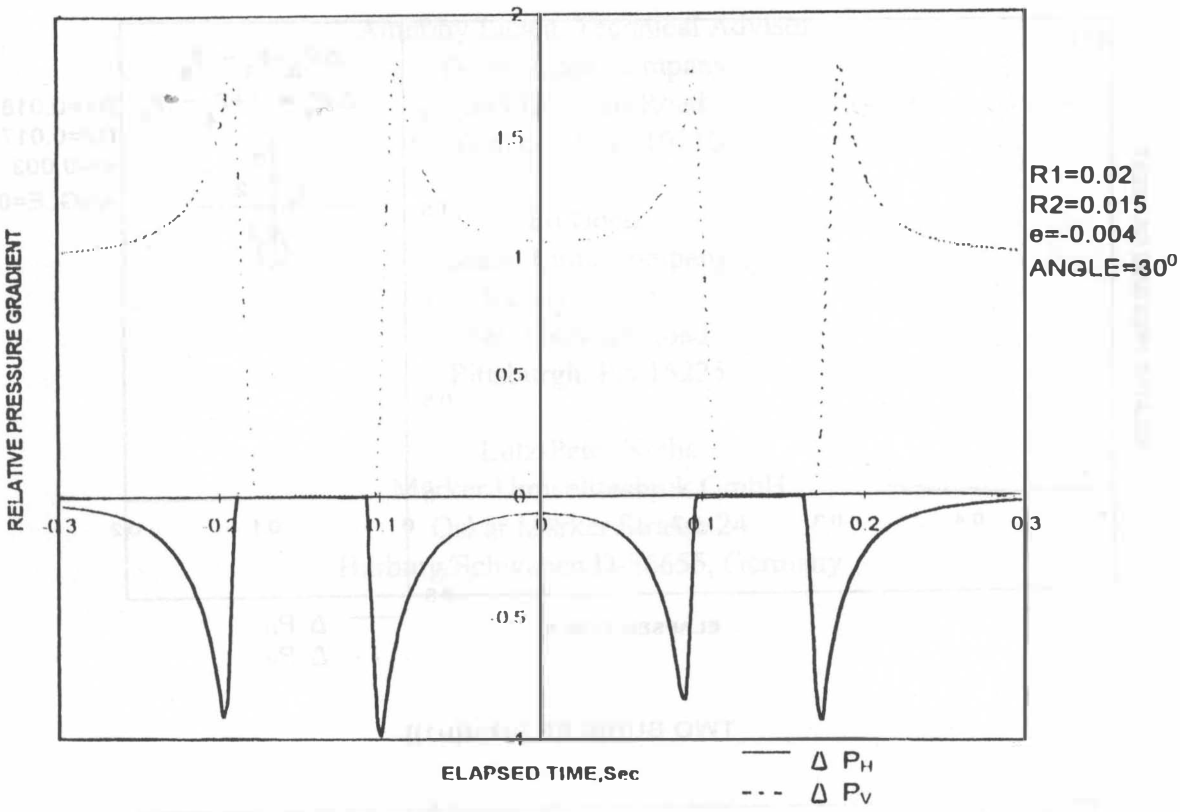
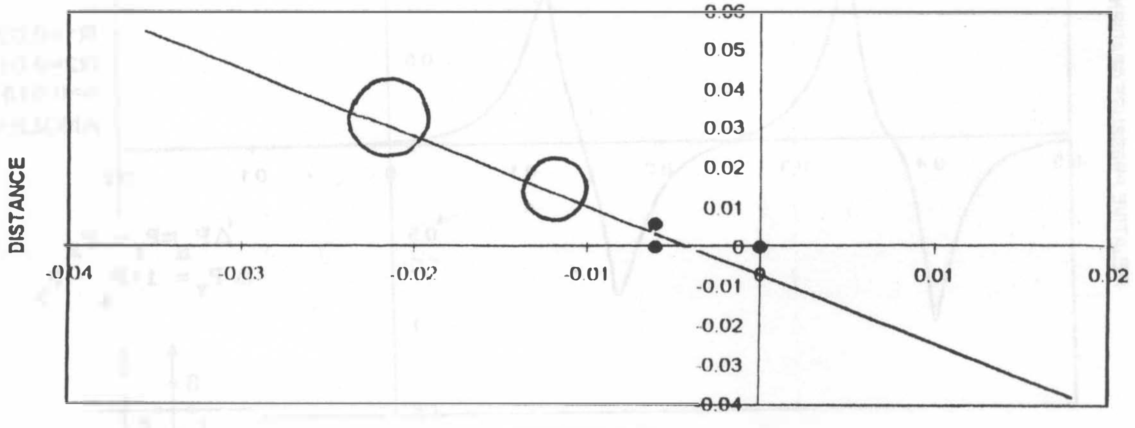


Fig . 8 Experimental recordings of vertical and horizontal differential pressures across a time interval of 9.9902 s in a freely bubbling 2-D bed (Sand , D_p = 402 μm , H_s = 0.55 m , Z = 0.32 m , and $U - U_{mf}$ = 0.18 m/s). The scale is from 1 REF to -1 REF for vertical and between 382.81 mREF and -117.18 mREF for horizontal differential.



TWO BUBBLES [u2=f(u1)]



PATH OF THE BUBBLES

Fig. 9 Simulated vertical and horizontal pressure gradient fluctuations for a bubble flowing obliquely and midway through the vertical differential probe.

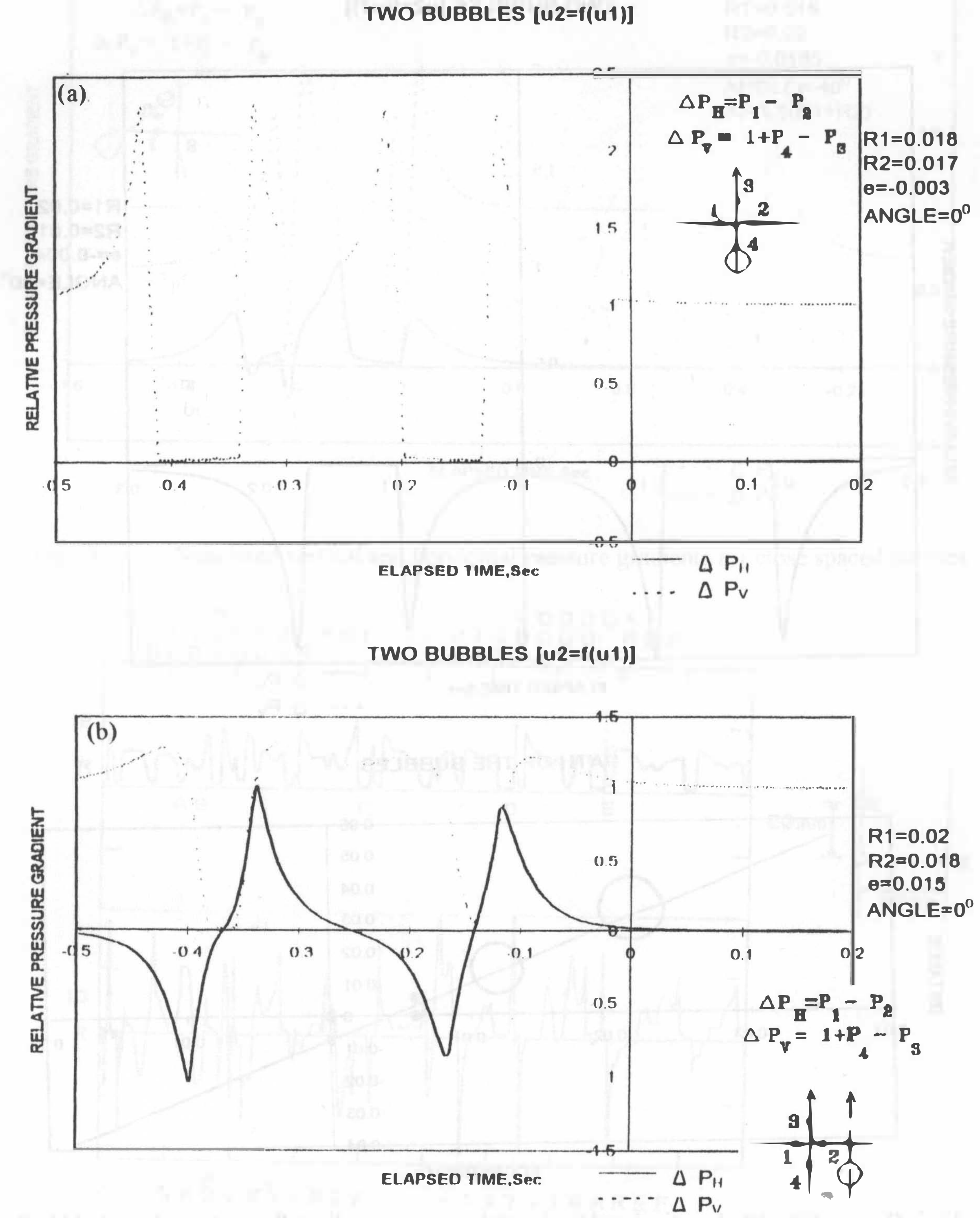


Fig. 10 Simulated vertical and horizontal pressure gradient fluctuations for (a) co-axial bubble hit and (b) eccentric hit.