OBSERVATION OF CROSS-SECTIONAL NON-UNIFORMITY IN FLUIDIZED BEDS USING TWO DIFFERENT IMAGING TECHNIQUES

Y. T. Makkawi[1], P. C. Wright[?1], V. Meeyoo[2], C. Dechsiri[3], E. van der Zwan[3], A. M. J. Paans[4] and A. C. Hoffmann[5]

1. **Department of Mechanical and Chemical Engineering, Heriot-Watt University, Edinburgh EH14 4AS, UK.**
2. **Centre for Advanced Materials and Environmental Research, Mahanakorn University of Technology, 51 Cheum Sampan Road, Bangkok 10530, Thailand**
3. **Department of Mathematics, University of Groningen, Blauwborgje 3, 9747 AC Groningen, Netherlands.**
4. **PET centre, University Hospital of Groningen, 9700 RB Groningen, Netherlands.**
5. **Department of Physics, Allegt. 55, 5007 Bergen, Norway**

INTRODUCTION

Gas-solid fluidized beds have been used for many decades to achieve good mixing between the solid material and the up-flowing gas. The latest sophisticated imaging techniques, such as tomographic systems, make it possible to analyze and visualize the solid dynamic movement and distribution inside in the bed. Taking fast images of the bed material during the fluidization process with high frequencies of 100 Hz usually does this. The main advantages of the imaging techniques are non-invasive nature, and suitability for industrial application where high temperature and pressure are required.

This study is based on comparing the work from two groups, each applying a different imaging technique. These two techniques are Positron Emission Tomography technique (*PET*) reported by Dechsiri et al. (1) and Electrical Capacitance Tomography (*ECT*) reported by Makkawi and Wright (2). Dechsiri et al. (1) reported an uneven axial dispersion of solids indicated by a shift in the profile of tracer solids towards one side of the column (i.e. poor cross-sectional distribution of the drag force exerted on the solids by the fluidizing gas). This problem probably exists in many industrially operating fluidized beds, but due to the limitation in monitoring techniques and difficulties in visual observation, this subject has not received enough attention. This problem is usually associated with three main defects: (1) low pressure drop across the distributor (2) poor distribution of holes in the distributor plate (3) inclination of the fluidization column, or mis-alignment of the distributor inside the column. Since the distributor used in the Dechsiri et al. (1) work was a sintered plate, with sufficiently high-pressure drop to ensure even distribution of the gas flow through it, we are left with the latter two possibilities.

Porous plates like that used by Dechsiri et al. (1) are notorious for giving problems with uniformity of the gas distribution. Dechsiri et al. (1) levelled their bed with a spirit level, and tests showed that their bed had to be tilted somewhat off the vertical to compensate for the cross-sectional mal-distribution they observed. This indicates that the distributor has to take

[?] Corresponding Author: Tel: +44 (0) 131 4518165; Fax:+ 44 (0) 4513129; E-mail: p.c.wright@hw.ac.uk

most of the blame for the gas mal-distribution in their particular system. The work reported in this present paper was undertaken to better understand the role of bed tilt on gas mal-distribution, and to compare the appearance of mal-distribution between two completely different tomographic methods: *ECT* and *PET*.

This laboratory study thus assesses the problem of cross-sectionally uneven gas distribution, giving rise to uneven axial dispersion of solids, as a result of inclination of the fluidization column, especially at low gas velocity. It also compares results from *ECT* studies of the cross-sectional bulk solids concentration in a column equipped with a precise tilting mechanism, with *PET* measurements under very similar operating conditions with the same particles and in the same bed, also exhibiting mal-distribution of the fluidizing gas.

BACKGROUND ON *ECT* AND *PET* TECHNIQUES

The *ECT* system is a sensitive scientific instrument based mainly on measuring the distribution of a two-phase mixture of non-conducting materials in a closed pipe or vessel. Typical applications of the system are for real time monitoring of the motion of fluids, such as pneumatic conveying systems and fluidized beds. The system produces online and off-line images at a high speed of 100 Hz, further technical details are given in Makkawi and Wright (2,3). The *PET* technique is another imaging technique based on tracking the dynamic movements of radioactive particles inside a vessel. The *PET* image is produced from gathered image slices of the bed; further details on this technique are given in Dechsiri et al. (1).

EXPERIMENTAL

As mentioned, two different imaging techniques have been used, at the University of Groningen in the Netherlands, the *PET* technique was used, and at Heriot-Watt University in UK the *ECT* technique. In both experiments, a column of 15 cm outer diameter filled with anion-exchange resin particles with a bed height ~20 cm above the distributor level (H_{st}~1.3 D_b) was used. Air at ambient conditions was introduced from the bottom of the bed with a fluidization velocity of 0.13 m/s (10% above the minimum fluidization velocity). Particle properties and operating conditions in both experiments are summarized in Table 1. The *PET* experiments in the Netherlands were carried out by placing a layer of radioactive particles at the bottom, at the middle and at the top of the bed. The fluidization gas was turned on at time t=0 and measurements were taken for a total of 5 minutes. Detailed experimental set-up and measuring procedures for the *PET* system is discussed elsewhere (1).

Table 1. Experimental conditions

Experimental unit	**Operating Condition**	
Column diameter	Outer=0.15 *m*, internal=0.138 *m*	
Particle	d_p = 470 ? *m*, $?_p$= 1.060 kg/m^3, material: Lewatit MP500	
Fluidizing Gas	Air at ambient condition	
Static Bed Height, H_s	20 cm	
Min. fluidization velocity, U_{mf}	~0.12 m/s	
	***ECT* system**	***PET* system**
Column height	1.5 *m*	0.35 *m*
Fluidization Velocity, *U*	~ 0.13, 0.16 and 0.33 *m/s*	~ 0.13 *m/s*
Distributor	Perforated PVC plate	Sintered bronze plate.
Experiment span	80 s	5 min

The fluidization column installed at Heriot-Watt University was especially designed to allow accurate and easy inclination of the column. The *ECT* system was also made to slide freely in the axial direction along the column for cross-sectional measurements at different levels. Additional measurements at 0.16 m/s and 0.33 m/s fluidization velocity and at four different axial levels were carried out to provide in-depth understanding on the solid distribution. The *ECT* experimental set-up is shown in Fig.1. Detailed information on the *ECT* measuring and pre-calibration procedure are given in Makkawi and Wright (2,3).

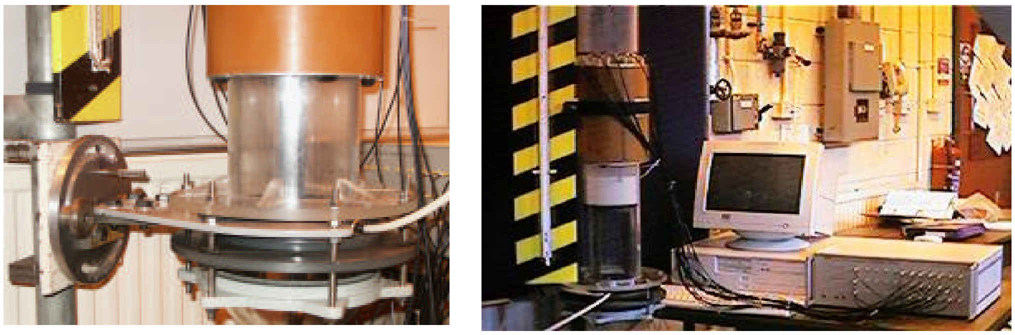
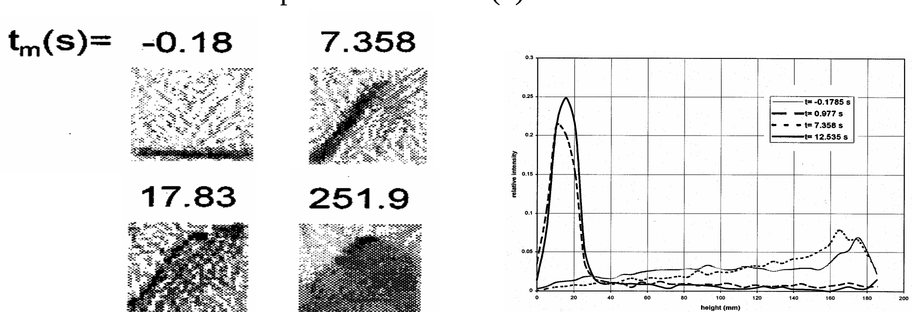


Fig. 1. Experimental set-up

RESULTS AND DISCUSSION

PET MEASUREMENTS

To investigate the dispersion of particles in the axial direction, a layer of radioactive particles was placed at the bottom of the bed (i.e. at the distributor level); the images were recorded for 5 minutes of operation. Fig.2a clearly shows a cross-sectionally uneven axial solid dispersion. We may assume that the bubbles travel primarily through one side of the column. Fig.2b shows the relative intensity as function of height, with time as the parameter. These results represent a cross-sectional position, at which the bubble activity was sufficiently high. The marked particles on the bottom will first move to the top, and then slowly move down until they are evenly distributed over the height of the bed. This is in agreement with the idea of Rowe et al. (4) that fluidization bubbles alone cause the particle movement in a fluidized bed. Particles move inside the wake of bubbles upward, and a downward movement of particles in the bulk compensates this upward movement. Further measurement with a layer of radioactive particles placed at the middle and top of the bed has shown the same behaviour. Detailed discussion of these results is reported elsewhere (1).



(a) (b)

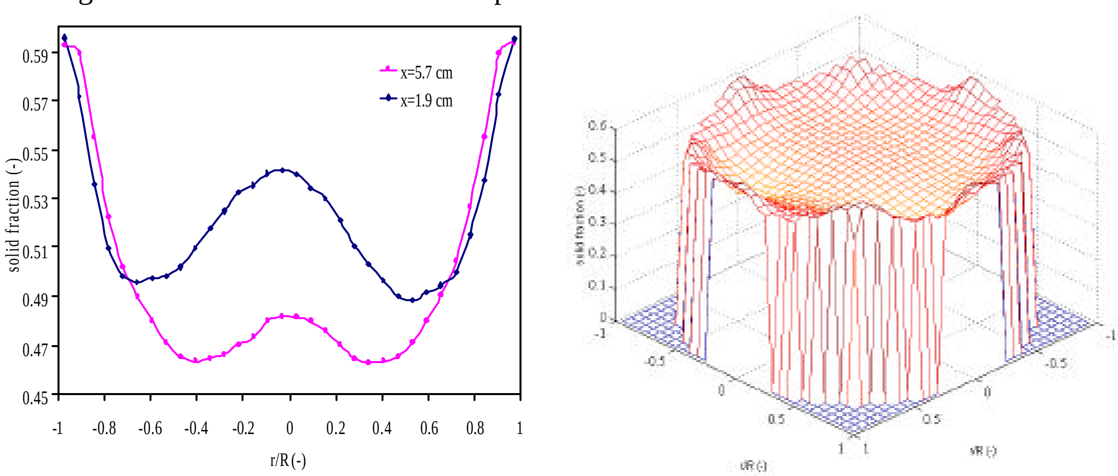
Fig. 2. Axial dispersion of a layer of radioactive particles at *U*~0.13 m/s (a) Images of the longitudinal as function of time (b) relative intensity as a function of height.

ECT MEASUREMENTS

While the *PET* technique shows the dispersion of marked particles through the bed, the *ECT* shows the cross-sectional distribution of the bulk solid density (or, in other words, the volumetric concentration of solids). In order to throw light on the *PET* results, and particularly the non-uniform axial dispersion, *ECT* measurements were carried out at different, slight inclinations of the column.

Vertically aligned column

The mean-time average solid distribution profile in a perfectly vertically aligned column is shown in Fig.3a. A clearly symmetrical profile can be seen in both measuring levels above the distributor. As expected, the gas moves rapidly upwards in the centre part of the column with high solid concentration at the walls. The cross-sectional mesh diagram of the solid distribution shown in Fig.3b confirms the uniformity of the bed material, which in turn should reflect a cross-sectionally uniform axial dispersion. It also seems that the bubbles initiating at the distributor are highly concentrated in a region between the dense-solid wall and the centre. Of course, in terms of dispersion, this means that the axial dispersion of solids is very poor at the walls and relatively better in the centre, while the annulus between *r/R*~?0.4 *r/R*~?0.8 is the region where the maximum axial dispersion occurs.

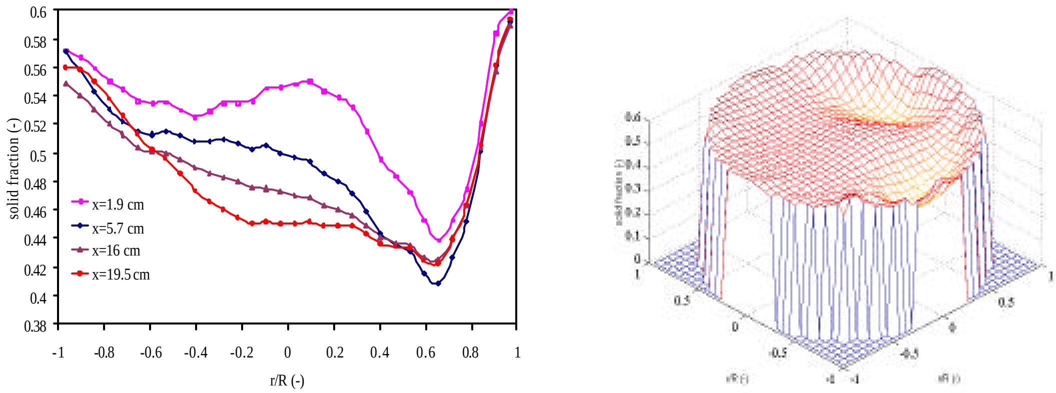


(a) (b)

Fig. 3. Solid distribution in a perfect vertically aligned column, gas velocity~0.13 m/s (a) solid fraction profile at two different levels (b) cross-sectional mesh at 1.9 cm.

Inclined column

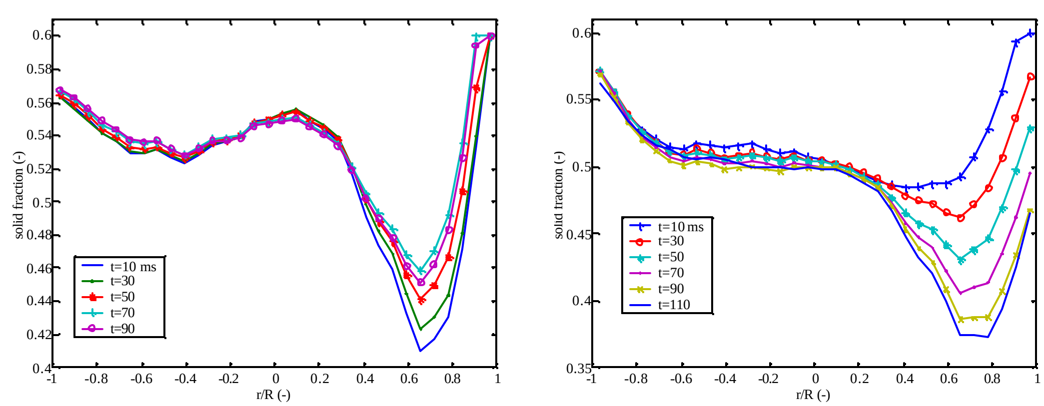
The *ECT* measurements were then carried out in a slightly tilted column with only $\sim 2^{o}$ deviation from vertical. Fig.4 shows the mean-time average solid distribution profile and the cross-sectional distribution. Severe defects in the material distribution can be noticed; this strongly demonstrates that a very minor tilt in the column or the distributor alignment is likely to cause significant problems with the cross-sectional distribution of the fluidizing gas. At approximately half the bed diameter the profile shows a distinct non-uniformity in the solid concentration, with a clear area of low concentration towards one side of the column. This observation probably corresponds with the observation using *PET* of a high dispersion of solids in one side of the bed as shown in Fig.2a. It is also interesting to note that the uniformity of the solid distribution improves with height as shown in Fig. 4a. This is in good agreement with some of the early reported studies on bubble propagation (5). In a freely bubbling fluidized bed, bubbles, which are initiated close to the wall at the distributor, tend to coalesce as they rise up, resulting in a concentration of bubbles in the bed centre.



(a) (b)

Fig. 4. Solid distribution in a column with 2° inclination, gas velocity~0.13 m/s (a) solid fraction profile at two different levels (b) cross-sectional mesh at 1.9 cm above the distributor.

The evolution of a bubble cycle with time, at the lower portion of the bed is shown in Fig. 5. As we know, the bubbling behaviour in freely bubbling fluidized beds is cyclic, with a short pause between each bubble cycle. The time dependent profiles shown in Fig. 5 is a selected consecutive time during a bubble passage as it passes across the upper and lower capacitance sensors. The rising bubble is the main source of axial dispersion of solids, but with an inclination, the weight of the solid material is concentrated in one side. Hence, the gas force exerted at the distributor level is not equally distributed, especially at low gas velocity where the drag force may not be sufficient to form a bubble, and this explains why the solid concentration remains high and almost unchanged with time as shown in Fig 5. At the lighter side of the bed, it is clear that the bubbles rise up with a sufficient drag force to push the solid material towards the top. These observations are in good agreement with the particle dispersion behaviour shown with the *PET* measurement.



(a) (b)

Fig. 5. Time evolution of solid distribution during a bubble cycle in a column with ~2° inclination, gas velocity~0.13 m/s (a) x=1.9 cm (b) x=5.7cm.

Effect of fluidization velocity

It is well known that the axial dispersion of solids is a function of the excess gas velocity. Therefore, the *ECT* system was used to investigate the effect of excess gas velocity on the material uniformity, which provides indirect information of the axial dispersion process. Fig.6 shows the solid distribution profile with excess gas velocities of 10%, 33% and 175%. It is clear that increasing the gas velocity can significantly decrease the cross-sectional non-uniformity as a result of inclination. Further increases in gas velocity may result in a complete disappearance of inclination effects. This could be an interesting area of research in order to establish a relation between the complete fluidization velocity (i.e. when the bed is free of defluidization zones) and the degree of column inclination.

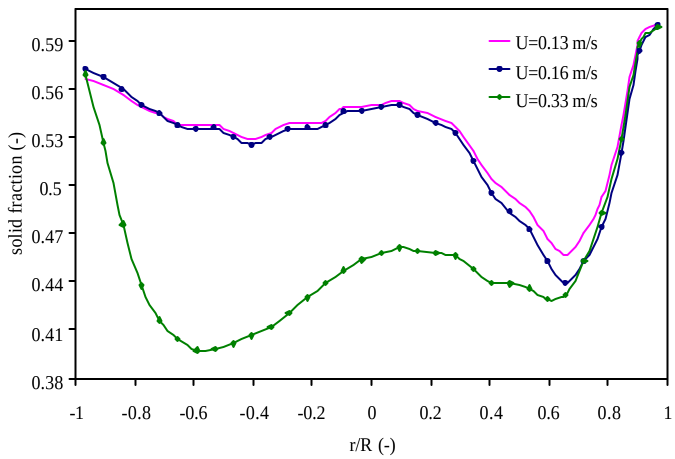


Fig. 6. Effect of gas velocity on the solid distribution profile at x=5.7 cm.

CONCLUSION

The *ECT* imaging technique has been applied in investigating cross-sectional non-uniformity of solid axial dispersion and bulk volume concentration in a bubbling fluidized bed. This study demonstrates that a very minor inclination as low as 2^o may lead to a dramatic change in the bed dynamics with a serious defluidization spots, especially at low excess gas velocity. Fluidizing the bed with higher excess gas velocities have shown a significant improvement in the bed uniformity. Further investigations are required to evaluate the effect of inclination on the general bed dynamics. This could also be used to establish a relation between the excess gas velocity and the defluidization phenomena, or in other words to quantify the minimum gas velocity required to overcome the deficiency in axial dispersion and bed uniformity in inclined columns.

To sum up, the possibility to visualize the flow structure in a three-dimensional manner has been successfully achieved by using and comparing two different imaging techniques. Both techniques, which are relatively new in the field of the particle processing industry has shown a great potential in detecting the detailed behaviour, and particularly cross-sectional non-uniformity in fluidized beds. The *PET* technique used in the study of Dechsiri et al. (2002), based on studying the dispersion through the bed of initially well-defined pulses of marked particles, has considerable potential in not only quantifying axial and radial particle dispersion, but also studying the cross-sectional and axial distribution of the gas and solids flow. Similarly *ECT* complements *PET* by giving an insight into solid concentration distributions and fluctuations.

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