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DETECTION OF GAS BYPASSING DUE TO JET STREAMING IN DEEP FLUIDIZED BEDS OF GROUP A PARTICLES

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ABSTRACT

Tests were conducted in deep fluidized beds with and without gas bypassing to develop a technique to detect jet streaming. By placing differential pressure (ΔP) transmitters in four quadrants across a section of the fluidized bed, it was found that jet streaming can be detected by analyzing the ΔP fluctuations.

INTRODUCTION

Bubbling fluidized beds are often selected as gas-solids reactors because of their intimate gas-solids contacting. The typical image of a fluidized bed is of gas voids rising through the center portion of the bed, transporting solids as they rise which causes a vigorous mixing of the gas and solids. This rapid mixing results in a nearly homogeneous temperature and gas composition in the bed.

However, this picture is not always the correct one. Tests (Knowlton (1), Karri et al. (2)) with deep beds of Geldart Group A particles have shown that bypassing of the fluidizing gas can occur when the beds are fluidized in the bubbling mode. The word “deep” is relative, and whether a certain depth of bed causes gas bypassing or not depends on several factors such as gas velocity, fines content, and the presence of baffles, etc. What occurs in the bed is that the gas preferentially flows in a streaming jet through one side of the bed, which results in extremely poor gas-solids contacting. The remainder of the bed is either defluidized or poorly fluidized. The gas bypassing phenomenon has rarely been described in the literature - perhaps because most laboratory beds are often not deep enough to cause bypassing. It appears that the reason for the bypassing is that the pressure head generated by a deep fluidized bed causes gas compression significant enough to cause defluidization of the solids. If gas bypassing occurs in industrial beds it can result in poor yields, afterburning in the freeboards of combustion reactors, poorly fluidized entrances to standpipes, and poorly fluidized discharge regions for cyclone diplegs.

Wells (3), described a gas bypassing flow regime that was observed in cold models. Wells also attributed gas bypassing to gas compression and proposed a mathematical model based on this theory. Particulate Solid Research, Inc. (PSRI)
(2) studied the phenomenon in more detail and also indicated that gas bypassing was due to gas compression in beds of Group A solids. PSRI (2) also showed how fines content, gas velocity and baffles affected gas bypassing.

Gas bypassing is detrimental to good fluid bed operation, and a method to predict when it is occurring would be beneficial to commercial operators of Group A beds. Pressure fluctuations have been used as a basis of measuring fluidization quality in a fluidized bed (Kai and Furusaki (4), Chong et al. (5), Gallucci et al. (6), Gheorghiu et al. (7), Van Ommen et al. (8) and Briens et al. (9)). This study investigated whether the standard deviation of the bed $\Delta P$ fluctuations could be used to determine when beds are jet streaming.

**EXPERIMENTAL**

Tests were conducted in a 0.9-m-diameter, 6.1 m tall test unit (Figure 1). Two air spargers were designed to provide a sufficient grid pressure drop to ensure good air distribution, while avoiding excessive pressure build-up in the plenum. For gas velocities up to 0.5 m/s, a 76-cm-diameter PVC pipe manifold was used with 50, 6-mm-diameter nozzles facing downward 30° from the vertical. For high gas flows, a 10.2-cm-diameter PVC ring sparger with 39, 13-mm-diameter nozzles facing downward 30° from the vertical was used. The ring sparger was installed 0.38 m above the pipe manifold. The primary cyclone had a 20-cm-diameter dipleg that returned solids onto the bed surface via an aerated trickle valve. The secondary had a 15.2-cm-diameter dipleg that returned solids to the bed via an automatic L-valve. A blower supplied fluidizing air through a 15.2-cm-diameter line. A butterfly valve downstream of a 76-mm-diameter orifice plate was used to control the air rate. Most low gas velocity tests were conducted with a 2.13 m long Plexiglas column section in to allow visual observation of gas bypassing. For safety, the Plexiglas section was replaced with a steel section for high gas velocity tests. Tests were conducted with FCC catalyst particles with a particle density of 1490 kg/m$^3$, fines contents of 3 and 12% less than 44 µm and median particle diameters of 80 and 74 µm, respectively, as shown in Figure 2.

Tests with the Plexiglas section showed that, when streaming, the bypass stream moved around the column at the wall. At some operating conditions there were multiple streams. Instrumentation ($\Delta P#1$, $\Delta P#2$, $\Delta P#3$ and $\Delta P#4$) was installed (Figures 1 and 3) to measure $\Delta P$ fluctuations across the entire column at four radial orientations (Figure 3) and, across four 61 cm long sections 90-degrees apart at the same orientation at a mid-point elevation of 1.52 m. $\Delta P$ fluctuations were measured using 6.3-mm-diameter purged steel tubes connected to Validyne DP15 transducers by 6.3-mm-OD plastic tubing. In addition to the $\Delta P$ fluctuations, bubble characteristics were measured using optical fiber bubble probes 1 and 2 inserted in the unit (180 degrees apart) at a height 1.52 m above the distributor. Bubble and $\Delta P$ signals were simultaneously normally sampled at 1000 Hz 3 minutes, but were also sampled for 30 minute durations to capture longer term trends.

**RESULTS AND DISCUSSION**

Figure 4 shows 10-minute signal traces of $\Delta P$ fluctuations measured across the entire bed at four orientations around the column for 3% fines FCC catalyst with a
static bed height of 3.05 m and a gas velocity of 0.61 m/s. The ∆P fluctuations at the four locations did not differ much because the pressure above the grid and the pressure in the freeboard were the same at every measurement location; the maximum difference in the standard deviations was about 13%. The measurements of ∆P fluctuations were more significant when measured across 61 cm length in the bed (Figure 5). The magnitude of the ∆P fluctuations should not vary with radial orientation in a well fluidized bed. The differences in the ∆P fluctuations in Figure 5 were caused by the presence of streaming in the unit. Locations closer to the gas bypass stream had significantly higher ∆P fluctuations. The signal traces clearly show the time periods when the bypass stream was at/or near a given measurement location. For example, gas bypassing was occurring near locations 3 and 4 between 60 and 200 s and then near locations 1 and 4 between 300 and 600 s. The orientations of the gas bypassing streams are evident in Figure 6, which plots the standard deviation of the ∆P fluctuations across the four 61 cm sections for data acquired continuously for 30 minutes vs. time. Bubble probes 1 and 2 which are close to ∆P measurement locations 1 and 3, respectively, also show periods of bubble/void activity in their signals (Figure 7). The data in Figure 7 were taken simultaneously with the data in Figure 6. The time periods of bubble/void presence in the traces in Figure 7 generally correspond to the durations of high standard deviations of ∆P fluctuations measured at the same two locations.

Figure 8 plots the standard deviation of the ∆P fluctuations across the 61 cm sections at radial orientations 1 to 4 as a function of superficial air velocity for a static bed height of 3.05 m and 3% fines FCC catalyst. There were differences among the standard deviations of ∆P fluctuations at the four orientations at nearly all the gas velocities - indicating that the bed was streaming. The differences in the standard deviation of ∆P fluctuations at the four radial orientations were not as significant when the 12% fines FCC catalyst was tested. Jet streaming was found to be less severe for the higher fines material. Increasing fines content or raising gas velocity lowers the intensity of streaming (Karri et. al (6)). A 3.05 m static bed height of 12% fines FCC catalyst was found to transition from streaming to uniform fluidization at a gas velocity of about 0.73 m/s. Visual observation of the fluidization behavior of the 12% fines FCC catalyst when the Plexiglas section was present showed that the gas bypass streams were smaller and of shorter duration. Under such conditions, the differences in the intensity of the ∆P fluctuations around the column, decreased significantly. Streaming diagnosis using the ∆P fluctuation signals is less accurate for high fines materials. In this case, the bubble probe signals shown in Figure 7 were used as a confirmation tool because they gave a more positive indication of fluidization behavior than the ∆P transmitters.

Figure 9 plots the radial bubble void fraction profiles for a bed height of 1.52 m, a gas velocity of 0.61 m/s, and for 3 and 12% fines FCC catalyst with static bed heights of 3.05 and 2.44 m, respectively. For the 3% fines FCC catalyst, the data taken at a fixed location at different times in a streaming bed varied depending on the location of the gas stream at the time of measurement. Therefore, the bubble radial voidage data was time dependent. In contrast, a 2.44 m static bed height of 12% fines FCC catalyst content fluidized uniformly at a superficial gas velocity of 0.61 m/s. This was confirmed by the symmetrical radial bubble void fraction profile.
Lowering bed height reduced the tendency to stream. Figures 10 and 11 (for 3 and 12% fines FCC catalyst, respectively) show the standard deviation of the $\Delta P$ fluctuations measured across the entire bed as a function of superficial gas velocity for various static bed heights. The transition points from streaming to uniform fluidization shown on the plots were established from measurements of $\Delta P$ fluctuations across 61 cm sections in the bed, and were confirmed by bubble probe traverses. The 3% fines FCC bed did not bypass only if the static bed height was lowered to about 1.22 m and the superficial gas velocity was raised to above 0.6 m/s. Raising fines content to 12% made it possible for taller beds to be fluidized without streaming. Static bed heights of 1.83, 2.44 and 3.05 m fluidized uniformly above superficial gas velocities of about 0.53, 0.69 and 0.73 m/s, respectively.

The velocity, $U_c$, corresponding to the peak standard deviation of $\Delta P$ fluctuations across a fluidized bed has often been used to indicate the onset of the transition from bubbling to turbulent fluidization regime. If streaming is present in a bed such $\Delta P$ fluctuations data may give erroneous results. Fig. 11 shows that the velocity at the peak standard deviation varies with bed height and that the fluidization behaviour to the left of the peak was streaming. To the right of the peak the fluidization behaviour may not necessarily be turbulent. Caution is, therefore, needed when utilizing $\Delta P$ fluctuations data for the determination of $U_c$. It is important that the fluidization behaviour under which measurements were taken is confirmed either visually or by use of probes or other means.

CONCLUSION

Jet streaming was detected in a 0.9-m-dia. fluidized bed of FCC catalyst particles by measuring differential pressure fluctuations across 61 cm heights in the middle of the bed at four locations around the column. The locations closer to the gas bypass stream had significantly higher standard deviations of $\Delta P$ fluctuations. For a given static bed height, $\Delta P$ fluctuations measured across the entire bed at the four radial orientations were not sensitive enough to detect gas bypassing in column. The radial bubble void fraction profile obtained by traversing the bed with two oppositely located bubble probes became symmetrical about the column axis when the bed transited from jet streaming to uniform fluidization. The use of $\Delta P$ fluctuations data to determine the transition velocity from bubbling to turbulent fluidization may be misleading if the bed is jet streaming.

REFERENCES

1. Knowlton, T. M., PSRI Video presented at Fluidization IX, Beijing, China, 2001

http://dc.engconfintl.org/fluidization_xii/95
8. van Ommen, M. Coppens, C. M. van den Bleek, Early warning of agglomeration in fluidized beds by attractor comparison, AIChE J., 46 (11), 2183 – 2197, 2000
Fig. 4. Traces of $\Delta P$ Fluctuations Across the Entire Bed at Four Radial Orientations for a Static Bed Height of 3.05 m at a Gas Velocity of 0.61 m/s

Fig. 5. Traces of $\Delta P$ Fluctuations Across 61 cm Sections at Four Radial Orientations for a Static Bed of 3.05 m at a Gas Velocity of 0.61 m/s
Fig. 6. Standard Deviation of $\Delta P$ Fluctuations Measured Across 61 cm Sections at Four Radial Orientations for 1800 s Calculated and Plotted for 60 s Intervals. Static Bed was 3.05 m and a Gas Velocity of 0.61 m/s Using 3% Fines FCC Catalyst

Fig. 7. Traces of Two Bubble Probe Signals Measured at Opposite Sides of Column 20 mm From the Wall at $z = 1.52$ m for a Static Bed of 3.05 m and a Gas Velocity of 0.61 m/s Using 3% Fines FCC Catalyst
Fig. 8. Standard Deviation of ∆P Fluctuations Across 61 cm Sections at Four Radial Orientations as a Function of Superficial Air Velocity for a Static Bed Height of 3.05 m and 3% Fines FCC Catalyst

Fig. 9. Radial Bubble Void Fraction Profiles at z = 1.52 m for Static Bed Heights of 2.44 and 3.05 m at a Gas Velocity of 0.61 m/s for FCC Catalyst with 3 and 12% Fines

Fig. 10. Standard Deviation of the ∆P Fluctuations Across the Entire Bed vs. Gas Velocity for Three Static Bed Heights Using 3% Fines FCC Catalyst

Fig. 11. Standard Deviation of the ∆P Fluctuations Across the Entire Bed vs. Gas Velocity for Three Static Bed Heights Using 12% Fines FCC Catalyst