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BYPASSING IN DEEP FLUIDIZED
BEDS OF GROUP A MATERIALS

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EFFECTS OF IMPOSED SOLIDS FLUX AND PRESSURE ON GAS BYPASSING IN DEEP FLUIDIZED BEDS OF GROUP A MATERIALS

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ABSTRACT

Tests were conducted in 0.6-m and 0.9-m-diameter units to determine the effect of imposed solids flux and system pressure on gas bypassing in deep beds of FCC catalyst particles. Imposed solids fluxes of up to 70 kg/m²s and freeboard pressures of up to about 200 kPag were used. Imposing a solids flux on the fluid bed increased the potential for gas bypassing, while increasing the system pressure had the opposite effect.

INTRODUCTION

Gas-solids fluidized beds have been extensively studied (1). Most of the gas in bubbling beds flows up the bed as bubbles with the remaining gas going into the emulsion phase (1). The rising bubbles cause rigorous solids mixing which leads to a uniform temperature in the bed and improves solids-gas contacting. Turbulent beds operate at higher gas velocities and have much fewer discrete bubbles than the bubbling beds. Turbulent bed fluidization is more chaotic, resulting in higher heat and mass transfer in the beds.

This picture of a fluidized beds is, however, not always correct. Deep beds of Group A materials can fluidize poorly, even though all the “criteria” for good fluidization are met. Wells (2) using 8 to 20% fines (material < 44 µm) FCC catalyst particles in a large semi-circular Plexiglas unit observed that the fluidizing air formed a “snake” of streaming gas a short distance above the grid and passed through the bed moving about the center of the bed and occasionally splitting and passing up the sides of the column, bypassing the mostly stagnant catalyst. The streaming flow was not affected by air distributor type but, it could be eliminated by lowering the bed height or installing horizontal baffles in the bed. Wells (2) attributed this form of gas bypassing to the compression of the emulsion phase by the pressure head developed in deep beds, and proposed a streaming flow mathematical model based on this theory.

Knowlton (3) used FCC catalyst particles with 4% fines (< 44 µm) in a 30-cm-diameter Plexiglas column and found that for bed heights exceeding about 0.9 m,
the fluidizing gas bypassed the solid bed and rose on one side of the column as a winding stream of fast moving bubbles or voids. The gas maldistribution could be corrected by increasing the fines content.

Karri et al. (4) and Issangya et al. (5, 6) using FCC catalyst particles found that gas bypassing could be eliminated by lowering the bed height, increasing the fines content, increasing the superficial gas velocity and installing well-spaced horizontal baffles in the entire bed. The studies also suggested that gas compression in deep beds and the resulting decrease in gas permeability to the emulsion phase were the reasons for gas bypassing. A computational fluid dynamic simulation by Cocco, et al. (7) provided a similar finding. Issangya et al. (5) diagnosed gas bypassing in a 0.9-m-diameter fluid bed from differential pressure fluctuations measured across four 61-cm sections located 90º apart around the column. Locations close to the gas bypass stream had a significantly higher standard deviation of the differential pressure fluctuations ($\sigma_{\Delta P}$).

Fluidized bed strippers are equipped with various types of baffles to promote gas solids contact. Baffles can prevent gas bypassing in the fluidized bed stripper, but gas bypassing can still occur above the stripping zone if the bed height above the top baffle is too high. Rall and Pell (8) studied fluid bed strippers using 8% fines equilibrium FCC catalyst particles and observed excessive system vibration in a test that was conducted without stripping baffles. The unit, however, functioned smoothly when the bed level was lowered from the initial height of 1.98 m to 1.22 m. Rivault et al. (9) conducted fluid bed stripper studies using 6.5% fines FCC particles. The bed height was 1.35 m and their maximum solids circulation flux was 108 kg/m²-s. The unit developed flow instabilities, significantly high pressure fluctuations, and flooding at some conditions when it was operated without baffles. Flooding, large-scale gas maldistribution, and “bridging” problems were observed by Senior et al. (10) in their study of tall FCC strippers. They suggested that the gas-flow maldistribution was a result of the emulsion phase gas compression in deep beds that was sufficient enough to defluidize a section of the stripper.

Most laboratory studies are conducted at ambient conditions with fluid beds that do not have solids flowing into and out of them. Commercial beds, however, almost always have solids continuously flowing through them and operate at elevated temperatures and pressures. For example, FCC regenerators usually operate in the turbulent fluidization regime at pressures between about 140 and 290 kPag, have solids fluxes of the order of 5 kg/m²-s, and the beds are generally 3 to 5 m deep. FCC strippers operate in the bubbling fluidized bed mode at gas velocities up to about 0.5 m/s with solids fluxes of about 50 to 175 kg/m²-s.

If gas bypassing occurs in industrial fluid beds, it can lower the gas/solids contacting efficiency and lead to poorly fluidized entrances to standpipes and the discharge regions of cyclone diplegs. Furthermore, gas bypassing can compromise the scale-up process. This paper discusses a study that was conducted to determine the effects of imposed solids flux and system pressure on gas bypassing in fluidized beds of Geldart Group A materials. Some aspects of this study were presented at the AIChE Annual Meeting (11).
EXPERIMENTAL

The effect of imposed solids flux was studied in a 0.9-m-diameter by 6.1-m-tall fluid bed unit shown in Figure 1(a). A 0.5-m-diameter primary cyclone with a 20-cm-diameter dipleg returned solids onto the bed surface via a trickle valve. The secondary cyclone, also 0.5 m in diameter, had a 152-cm-diameter, 4.36 m long dipleg that returned solids via an automatic L-valve at a height of 3.13 m above the gas distributors. The solids circulating loop consisted of a 9.8-m-long by 30-cm-diameter steel standpipe connected to a 30-cm-diameter, 24 m tall PVC riser with a wye-section. The solids flow rate was controlled by a pneumatically-actuated slide valve located at the bottom of the vertical section of the standpipe. The imposed solids flux in the fluid bed was measured in the riser at height 13.2 m above the solids entry point by traversing an extraction probe across the riser. The solids flow rate was the integrated average of the net of the upward and downward flow rates. The extraction gas velocity in the extraction probe was 14.3 m/s, equal to the riser superficial gas velocity (12).

The effect of system pressure was studied in a 0.6-m-diameter, 6.1-m-tall fluidized bed unit shown in Figure 1(b). The first stage cyclone had a 25-cm-diameter dipleg that returned solids to the bottom of the column via an automatic L-valve. Air exiting the first-stage cyclone passed through two, parallel 15-cm-diameter second-stage cyclones and then through a pair of parallel air filters. A wye-fitting joined the second-stage cyclone diplegs to a 76-mm-diameter line that returned the solids to the primary cyclone dipleg with another automatic L-valve. The air exiting the two filters entered a line that branched into a 102-mm-diameter line that had a butterfly valve and a 25-mm-diameter line with a pneumatically-operated pressure control needle valve. The operating pressure was set manually with the butterfly valve and then fine-tuned by the needle valve.

Fluidization behavior in both units was characterized from differential pressure (ΔP) fluctuations and radial bubble void fraction profiles. Pressure drop fluctuations were measured across the entire column at four radial orientations, one for each quadrant, and across 61-cm-long sections at the same four radial orientations at a mid-point elevation 1.52 m above the air distributor. For static bed heights 1.83 m and lower, the mid-point elevation was lowered to 0.6 m. The differential pressure fluctuations were measured with 6.3-mm-diameter purged steel tubes connected to high-frequency Validyne DP15 transducers by 6.3-mm-diameter plastic tubing. One optical fiber bubble located at location 1 and another at location 3 were simultaneously traversed from the wall to the center. The bubble and the differential-pressure fluctuation signals were simultaneously sampled at 1000 Hz for durations of 3 minutes. Tests were conducted with FCC catalyst powder with a particle density of 1490 kg/m³, fines contents (F44) of 3, 4 and 9% < 44 µm, and median particle diameters of 82, 81 and 80 µm, as shown in Figure 2.

RESULTS AND DISCUSSION

Influence of Imposed Solids Flux on Gas Bypassing

A test at a static bed height of 1.22 m and zero imposed solids flux found that gas bypassing could be eliminated if the superficial gas velocity ($U_g$) was equal to or
greater than about 0.76 m/s. When the test was repeated with an imposed solids flux (Gs) of 64.6 kg/m²s, gas bypassing occurred at all gas velocities. The gas bypassing stream moved around the bed close to the wall just as it did in the beds with no solids flux. Figure 3 shows the $\sigma_{\Delta P}$ as a function of gas velocity for $Gs = 0$ and $Gs = 64.6$ kg/m²s. The standard deviation of differential pressure fluctuations ($\sigma_{\Delta P}$) for 64.6 kg/m²s were higher than for $Gs = 0$ because of gas bypassing. Figure 3 also compares the $\sigma_{\Delta P}$ for a static bed height of 2.44 m and $Gs = 0$, 33.8 and 68.5 kg/m²s. Gas bypassing was present at all conditions. The $\sigma_{\Delta P}$ increased with increasing imposed solids flux at all gas velocities, which indicates that imposing more solids flow in an already gas bypassing bed caused more gas to bypass the solids phase.

For a 2.44 m static bed height, the $\sigma_{\Delta P}$ as a function of gas velocity for 3% and 9% fines contents are compared in Figure 4. The tendency for gas bypassing as reflected in the magnitude of the standard deviation of the pressure drop fluctuations, decreased when the fines content was raised from 3% to 9%. Figure 5 is a plot of the streaming-to-uniform fluidization transition points for 9% fines FCC catalyst particles at a superficial gas velocity of 0.9 m/s. At zero imposed solids flux and a static bed height of 2.44 m, a gas velocity of 0.9 m/s was needed to fluidize the bed without streaming. There was a gradual decrease of the transition static bed height as the imposed solids flux was increased. For example, increasing the imposed solids flux from 0 to 64.7 kg/m²s decreased the transition static bed height from 2.44 m to about 1.53 m.

Why would imposing a solids flux through a fluid bed initiate or strengthen gas bypassing? It appears that the downward momentum of the solids as they flow through the bed makes it more difficult for the counter-current gas to permeate the bed solids mass.

**Effect of Pressure on Gas Bypassing**

Figure 6 shows the $\sigma_{\Delta P}$ across the 61-cm sections at radial locations 1, 2, 3 and 4 for the 3% fines FCC catalyst powder as a function of freeboard pressure. The static bed height was 3.66 m. There were significant differences among the $\sigma_{\Delta P}$ at the four quadrants at low pressure, which indicates that gas bypassing was occurring in the bed. The magnitude as well as the difference in the $\sigma_{\Delta P}$ around the column initially decreased sharply and then more gradually as the system pressure was raised. The $\sigma_{\Delta P}$ decreased from about 15 to 38 cm of water at 24.1 kPag to about 10 to 18 cm of water at 68.9 kPag. There was not much difference in the intensity of the pressure drop fluctuations among the four circumferential locations at pressures greater than about 103.4 kPag. The $\sigma_{\Delta P}$ changed from only about 10 cm of water at 103.4 kPag to about 5 cm of water at 206.8 kPag. The initial sharp decrease in the intensity of the pressure fluctuations corresponded to the transitioning of the bed from gas bypassing to uniform fluidization while the small change that followed at a pressure greater than 103.4 kPag was likely an effect of pressure on bed hydrodynamics, such as a decrease in bubble size.
Figures 7 shows, for the same material, bubble probe signal traces at radial location 3, which was 2.54 cm from the wall. The freeboard pressures were 24.1, 68.9, 137.8 and 206.8 kPag for a static bed height of 3.66 m, and the superficial air velocity was 0.46 m/s. The bubble probe data were simultaneously taken with pressure fluctuation data, as shown in Figure 6. At a pressure of 24.1 kPag the signal trace had significantly long periods of bubble/void activity suggesting that large amounts of gas were flowing upward close to the wall, which corresponds well with the high pressure drop fluctuations shown in Figure 6. The extended periods of bubble/void activity decreased as the pressure was increased, showing that the bed transited from a gas bypassing mode to uniform, smooth fluidization as the freeboard pressure was raised from 24.1 to 206.8 kPag.

Figure 8 shows two radial bubble void fraction profiles measured along radial orientations 1 to 3 for low (34.5 kPag) and high (137.9 kPag) freeboard pressures. The profile at 137.9 kPag was nearly parabolic with the highest bubble void fraction in the center of the unit suggesting an absence of gas bypassing, while the profile at 34.8 kPag indicates significant gas maldistribution due to gas bypassing.

Figure 9 shows the streaming-to-uniform fluidization system pressure for a given static bed height at superficial gas velocities of 0.3 and 0.46 m/s. A fluidized bed initially at a static height of 3.66 m with 3.2% fines and operating at a superficial gas velocity of 0.46 m/s transitioned from streaming to uniform fluidization at a freeboard pressure of about 103.4 kPag. The transition pressure for the same bed height and 4% fines FCC catalyst particles at a superficial gas velocity of 0.3 m/s was about 137.9 kPag. Similarly, the transition points for a 2.13 m static bed height at superficial gas velocities of 0.3 and 0.46 m/s and a fines level of 4% were about 68.9 and 34.5 kPag, respectively. Two data points obtained in a 0.3 and the 0.9-m-diameter test units are also included in Figure 9. The relationship between the static bed height and freeboard pressure at the transition point is nearly linear.

Gas bypassing occurs in deep beds of Group A materials because the gas compression caused by the fluid bed pressure head is sufficient to lead to defluidization in the lower part of the bed (Karri et al., 2004). Since the gas compression ratio is proportional to the absolute pressure ratio between the bottom and top of the bed, it follows that high pressure fluid bed systems will be less susceptible to gas bypassing. The data plotted in Figure 9 correspond to absolute pressure ratios of between 1.056 and 1.126 and suggest that gas bypassing did not occur for the FCC particles if the increase in absolute pressure from top to bottom of the bed is less than about 12.6%.

**Conclusion**

Imposing a sufficient solids flux through a uniformly fluidized bed of FCC catalyst particles can cause a bed to exhibit gas bypassing. Imposing a solids flux in an already streaming bed caused more severe gas bypassing. At a given imposed solids flux, the tendency for gas bypassing decreased if the gas velocity was raised or the fines content was increased. Increasing system pressure eliminates or decreases gas bypassing in deep beds of FCC catalyst powder.

**REFERENCES**


Figure 1. Schematic drawings of (a) 0.9-m and (b) 0.6-m-diameter fluid beds (See experimental section for dimensions)
Figure 2. Particles Size Distributions of the FCC Catalyst Particles Used in the Testing

Figure 3. Static Bed Height for No Gas Bypassing versus Fines Content for \( U_g = 0.6 \) m/s and \( F_{44} = 3\% \).

Figure 4. \( \sigma_{\Delta P} \) versus \( U_g \)

\( D = 0.9 \) m, \( G_s = 0, 64.7 \) and 68.5 kg/m\(^2\)s, \( H = 2.44 \) m and \( F_{44} = 3 \) and 9\%)

Figure 5. Static Bed Height for No Gas Bypassing at \( U_g = 0.91 \) m/s Plotted Against Imposed Solids Flux for 9\% Fines FCC Catalyst Particles
Figure 7. Bubble Probe Traces at Radial Orientation 3 for $P = 24.1, 68.9, 137.9$ and $206.8$ kPag ($D = 0.6$ m, $z = 1.52$ m, $H = 3.66$ m, $F44 = 3\%$ and $Ug = 0.46$ m/s)

Figure 6. $\sigma_{\Delta P}$ Across 61 cm Sections at Four Radial Orientations versus Pressure ($D = 0.6$ m, $z = 1.52$ m, $H = 3.66$ m, $F44 = 3.2\%$ and $Ug = 0.46$ m/s)

Figure 8. Radial Bubble Void Fraction Profiles at $z = 1.52$ m for $P = 34.5, 137.9$ kPag, $Ug = 0.3$ and 0.46 m/s and $F44 = 4\%$ and 3.2, Respectively. ($D = 0.6$ m, $H = 3.66$ m)

Figure 9. Static Bed Height for No Gas Bypassing versus Freeboard Pressure for $Ug = 0.3$ and 0.46 m/s and $F44 = 3.2$ and 4\%.(Above lines = Gas Bypassing)