Understanding Streaming Flow in Deep Fluidized Beds

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Abstract

Gas streaming is the severe bypassing of gas that can occur in deep, bubbling fluidized beds. Gas bypassing consists of a large jet that precesses around the walls of the fluidized bed. The remainder of the bed is either defluidized or poorly fluidized. In some case, multiple gas jets can occur in the bed. This gas streaming phenomenon is not typically seen in small laboratory beds, as bed heights in the laboratory beds are usually not high enough to produce this behavior. This gas bypassing tends to be an issue for large pilot plants or commercial units where fixing the problem is more expensive.

To better understand the gas bypassing behavior in deep fluidized beds, tests were conducted in a 0.3 and 0.9 meter ID columns at varying bed heights and fines levels. In addition, a MP-PIC model, using Barracuda™ from Arena-Flow, was used to further examine the role and mechanism of gas bypassing in these fluidized beds. Details of possible mechanisms and possible techniques for detecting gas-bypassing are presented.

Introduction

It is often assumed that fluidized beds offer good solids mixing and heat transfer. Similarly, it is assumed that a fluidized bed that runs well on the pilot scale will run well on a commercial scale. However, recent studies at Particulate Solid Research, Inc. (PSRI), suggest that these two assumptions may not always be valid. Deep beds of Geldart Group A powders have been found to exhibit gas bypassing or jet streaming under some conditions. What occurs is that the gas is diverted so that it flows through only a portion of the bed. One portion will exhibit almost turbulent fluidization while another portion of the bed is virtually stagnant, as illustrated in Figure 1. The result of this phenomenon is severe gas bypassing resulting in poor gas-solid contacting (i.e., low productivity for many systems).

There are some limited studies in the literature that have highlighted this effect. Senior et al [1] stated that gas compression and the resulting bypassing phenomenon resulted in several types of operating problems observed in tall FCC strippers. Wells [2], described the existence of a streaming, gas bypassing flow regime that was observed in cold models. Wells attributed this regime to the compression of the emulsion phase by the pressure head developed in deep beds, and proposed a mathematical model based on this theory.

To understand the gas bypassing phenomenon and the subsequent poor gas-solids contacting, PSRI embarked upon a program to evaluate the effects of several system parameters on gas bypassing [3,4]. It was observed that gas bypassing was strongly dependent on the bed height as well as other factors such as gas velocity, baffle configuration, and fines concentration. This was not found to be a start up effect. Gas bypassing could occur any time in a well fluidized bed if any of these factors are changed such as fines removal or increasing the bed height. It appears that gas bypassing is the result of the pressure head generated by a deep fluidized bed. This causes enough gas compression to defluidize a significant portion of the bed.

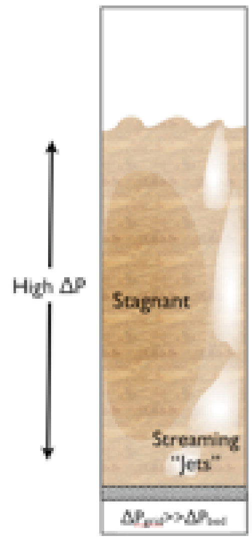

Figure 1: Illustration of the gas bypassing concept in a large fluidized bed.

The potential seriousness of gas bypassing in fluidized beds is that lab- and perhaps pilot-scale units may never observe this behavior. Small scale units may not have the bed height that results in gas bypassing. Thus, productivity recorded in these units many not correspond favorably to that in commercial scale plants. This opposes conventional thinking where larger fluidized beds are less influenced by wall effects and generally operate better than the small diameter units. Hence, it is critical that gas-bypassing is understood and predicted, when designing a commercial-scale fluidized bed, even when that data from smaller scale units suggest the bed should be well-fluidized.

Experimental

The deep bed studies were conducted in two 6.1 meter tall fluidized bed units of 0.3 and 0.9 meter diameters. The schematics of these units are shown in Figure 2. The smaller was a Plexiglas unit that had a gas distributor constructed of 13 bubble caps arranged in a square pitch pattern. Each of the caps had three, 8-mm-diameter tubes inclined downward at 30° from the vertical. The 0.9-meter diameter unit was constructed of steel and had two air distributors that were operated one at a time. For air velocities up to 0.5 m/s, a 76-cm-diameter PVC pipe manifold with 50, 6-mm-diameter nozzles facing downward 30° from the vertical was used. 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. Precautions where taken to ensure that the pressure drop across the grid was at least equal to 30% the pressure drop across the bed.

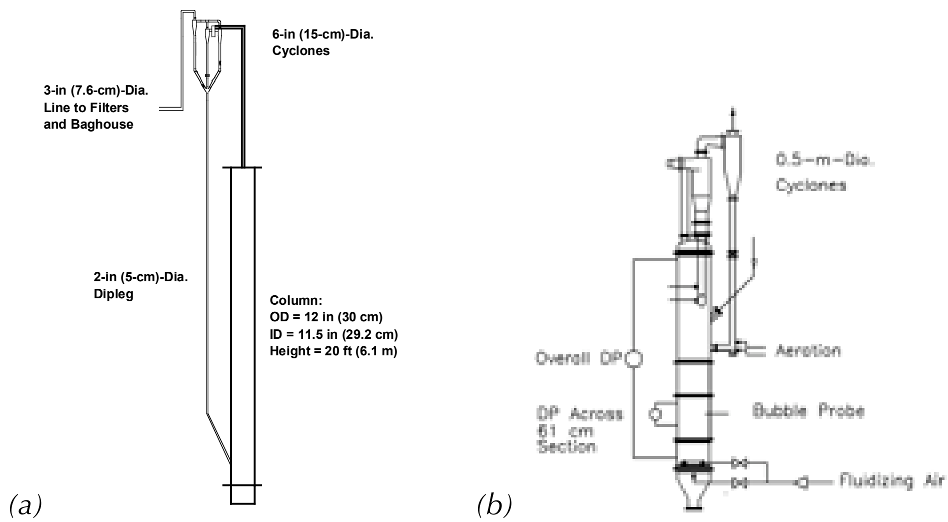

Figure 2: Schematics of the (a) 0.3 meter diameter by 6.1 meter and the (b) 0.9 meter diameter by 6.1 meter fluidized bed test units.

A Validyne fast response transmitter was used to measure differential pressures and differential pressure fluctuations from a point immediately above the distributor to the freeboard of the bed. The pressure taps for the transmitter were purged with air at a value of approximately 3 m/s. The differential pressure signals were sampled at 1000 Hz for a period of 3 minutes.

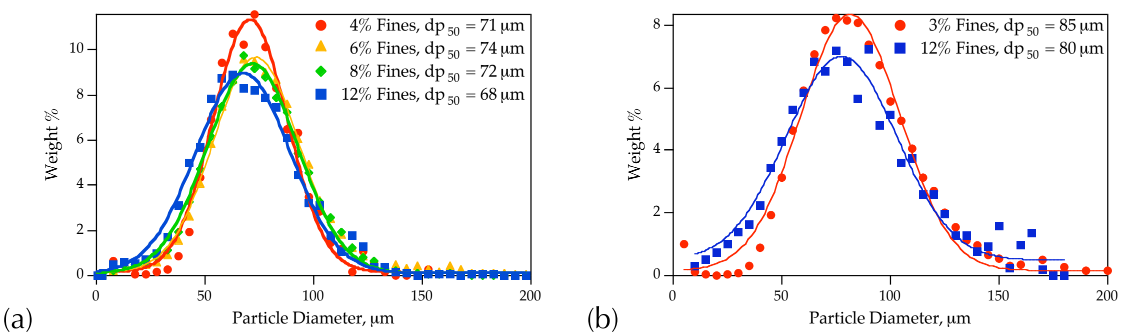

Figure 3: Particle size distribution of (a) light FCC powder with 4, 6, 8 and 12% fines, and (b) heavy FCC powder with 4 and 12% fines.

Light and heavy FCC catalysts with different fines (material less than 44 microns in size) contents were used as the test materials. The light FCC catalyst was used in the 0.3 meter diameter unit. It had a dp_{50} of 70 µm and a particle density of 1200 kg/meters^3. The fines contents of 4, 6, 8, 11, and 12% by weight were studied. The heavy FCC catalyst had a particle density of 1490 kg/meters^3 with a fines content 3 and 12%. and a dp_{50} of 82 µm. Figure 3 shows the particle size distributions for both FCC powders.

Results and Discussion

In a glass, Plexiglas or acrylic unit, evidence of gas bypassing is obvious. One portion of the bed is clearly in “turbulent” fluidization. Bubbles are erratic and substantially elongated and inconsistent in shape. The other portion of the bed is stagnant or defluidized. Very little gas or solid motion is detected.

Unfortunately, it is rarely possible to detect gas bypassing in commercial fluidized beds with conventional instrumentation. It was not possible to determine if gas bypassing were occurring by measuring the pressure-drop-per-unit-length ($\Delta P/Lg$) across a portion of the bed. This value was essentially the same for beds that fluidized uniformly and for beds in which gas bypassing occurred. Even the entrainment rates were found to be similar.

However, using the high speed Validyne pressure transducer with a high speed data acquisition card; other responses were found to indicate the presence of gas bypassing. As shown in Figure 4, the standard deviation of the pressure signal in the 0.9 meter diameter fluidized bed was substantially higher when gas bypassing was present near the pressure transducer. Standard deviations increased about 2X compared to the cases when gas bypassing was not present.

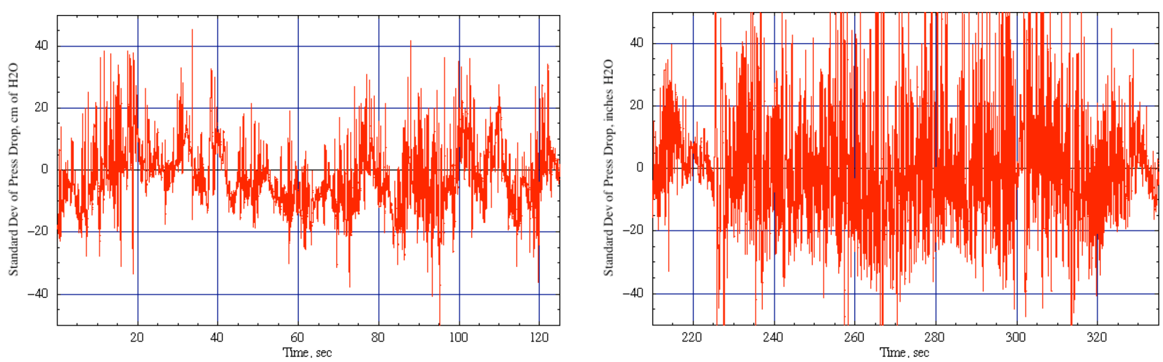

Figure 4: Standard deviation of the pressure drop signal without (left) and with (right) the presence of gas bypassing in the 0.9 meter diameter fluidized bed.

A power spectrum analysis of the waveforms in Figure 4 also showed a definitive difference between the pressure signal representing gas bypassing and no gas bypassing, as shown in Figure 5. The power spectra suggest that gas bypassing not only increases the amplitude of the standard deviation of the pressure signal, it also produces higher frequency responses in the pressure signal. Figure 5 confirms that, in the presence of gas bypassing, some portions of the fluidized bed may behave similar to a turbulent fluidized bed where pressure responses are expected to be more chaotic with a wider range of inherent frequencies [5].

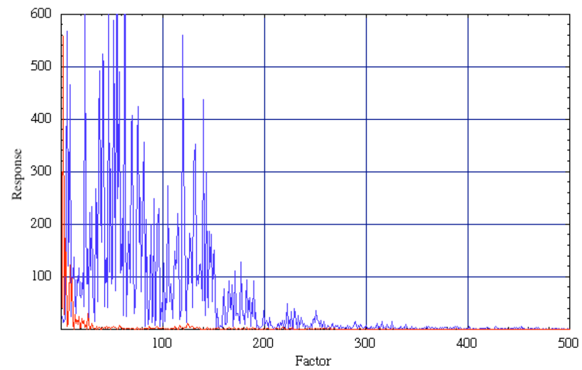

Figure 5: Power spectrum analysis with Hanning filtering for a pressure response curve (Figure 4) indicative of a fluidized bed with (blue) and without (red) gas bypassing.

Gas bypassing was found to be dependent on the bed height. As shown in Figure 6, a shallow bed may exhibit uniform fluidization typical of a bubbling fluidized bed. This is indicated by the lower variance observed with the differential pressure across the bed over a wide range of superficial gas velocities. When the bed height was increased to two meters in depth, the pressure fluctuations increased substantially, especially with higher superficial gas velocities.

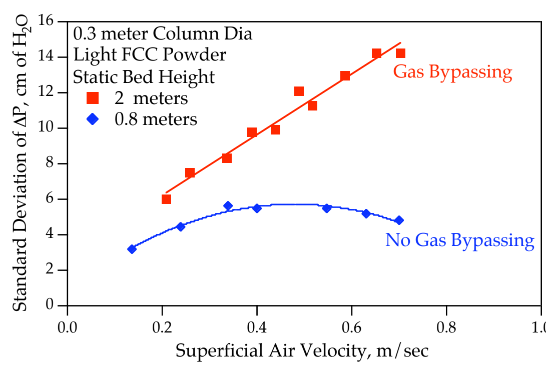

Figure 6: Pressure fluctuations, as an indication of gas bypassing, with respect to superficial gas velocities for a fluidized bed of light FCC powder (6% fines) with a bed height of 0.8 and 2.0 meters in the 0.3 meter diameter fluidized bed unit.

If gas compression is the cause of gas bypassing in deep beds, it would be expected that adding fines to the bed would affect the height at which gas bypassing begins. Adding fines to a Group A material results in decreasing the density at minimum bubbling (ρ_{mb}) relative to the density at minimum fluidization (ρ_{mf}). This means the emulsion phase contains more gas, and can undergo more gas compression before defluidization occurs. Thus, it would be expected that increasing the fines content of a Group A material would allow operation in deeper beds before gas bypassing occurs.

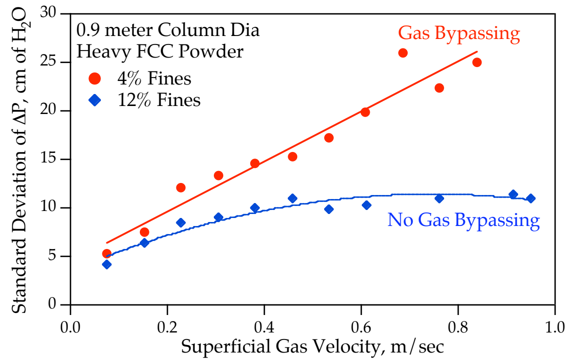

Figure 7: Pressure fluctuations, as an indication of gas bypassing, with respect to superficial gas velocities for a fluidized bed of heavy FCC powder with a fines content of 3 to 12% in the 0.9 meter diameter fluidized bed unit.

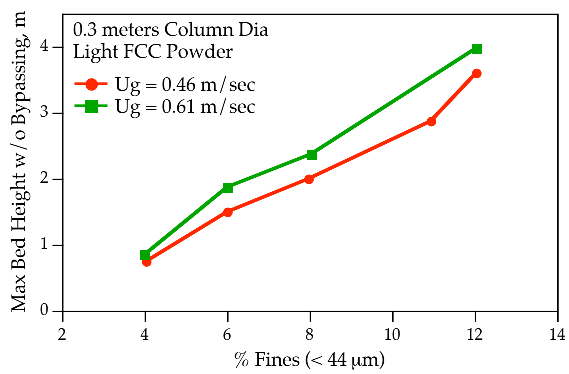

Figure 8: Minimum bed height needed to prevent gas bypassing with respect to fines concentration and superficial gas velocity in the 0.3 meter diameter unit with light FCC powder.

This was confirmed with several tests that determined the minimum height at which gas bypassing occurred for 3 and 12% fines contents of the heavy FCC catalyst material in the larger 0.9 meter diameter bed. As shown in Figure 7, the standard deviations of the pressure drop fluctuations for the bed containing 12% fines were very low. No gas bypassing was observed in this bed. However, when the fines content was reduced to 3%, the pressure fluctuation more than doubled. The lower fines content resulted in a poorly fluidized bed due to gas bypassing.

Figure 8 further shows the role fines content has on gas bypassing. In the smaller 0.3 meter diameter bed with the light FCC powder, the bed height was lowered until gas bypassing was no longer observed (bed transited into uniform fluidization). It was found that gas bypassing occurred in beds deeper than 0.8 meter for a fines content of 4% and a gas velocity of 0.46 m/s. Increasing the fines content to 12% increased the minimum bed height at which bypassing occurred to approximately 3.7 meters for the same gas velocity. The increase in bed height before gas bypassing appears is approximately linear with respect to fines content for gas velocities of 0.46 and 0.61 m/s.

The effect of baffles on gas bypassing in deep beds was also investigated with the light FCC powder having 4% fines. Figure 8 indicates that beds deeper than approximately 0.76 meter began to jet stream for a fines content of 4%. Therefore, two horizontal baffles made of steel grating (25 mm x 102 mm opening) were added to the test column to determine their effect on jet streaming. Because gas bypassing occurred for beds deeper than 0.76 meter with the 4% fines content catalyst, the baffles were located 0.76 meter apart. The first baffle was located 0.76 meter above the gas distributor, and the second baffle was located 0.76 meter above the first baffle. The static bed height was about 1.52 meters

As shown in Figure 9, the bed containing the baffles did not exhibit gas bypassing whereas a bed of the same height without baffles had significant bypassing. The apparent reason for the effectiveness of the baffles in eliminating gas bypassing is that the grating causes the less permeable solids to separate as the solids flow around the grating. This separation exposes more catalyst surface area, allows the gas to permeate the solids and makes it easier to aerate the solids and prevent defluidization.

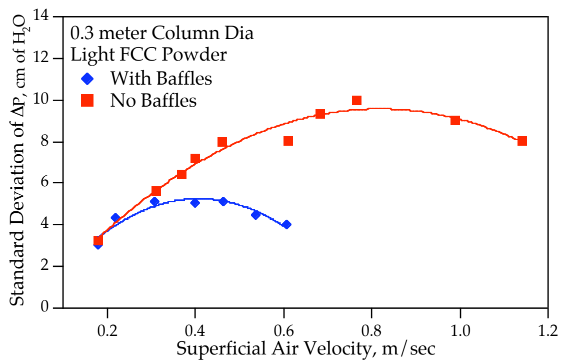

Figure 9: Gas bypassing, as indicated by pressure fluctuations, of a fluidized bed with (red) and without (blue) horizontal baffles at various superficial gas velocities.

The 0.9 meter diameter test unit with the heavy FCC powder was modeled, by Arena-Flow [6], using Barracuda™, a computational fluid dynamics code based on MP-PIC [7,8] for modeling gas-solid hydrodynamics. Barracuda™ was used to explore the role fines level (see Figure 3) had on gas bypassing, as indicted in Figure 7. Barracuda™ has the capability of modeling the entire particles size distribution and thus makes it ideally suited to explore the roles of particle fines with gas bypassing. As shown in Figure 10, Barracuda™ was able to discern the role fines level had on gas bypassing. When simulating a fluidized bed with FCC powder having a fines level of 3%, extreme gas bypassing was observed. The surrounding bed had a solids volume fraction of 0.5 and higher suggesting that part of the bed is near defluidization (with a packing fraction of 0.63). In addition, the simulation showed the gas bypassing stream precessed around the bed which has also been observed in PSRI's experiments.

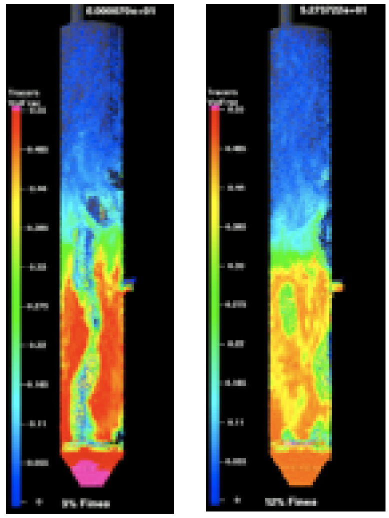

Figure 10: Barracuda™ simulations of a fluidized bed containing 4% (left) and 12% (right) fines.

Similarly, when the particles size distribution contained 12% fines, Barracuda™ accurately predicted that the bed would not undergo gas bypassing. Although large bubbles were detected in the simulations, the bed solids volume fraction never exceeded 0.45, which suggests that the entire bed remained fluidized. In addition, bubbles were observed through out the entire bed at one time or another.

Conclusions

Commercial scale fluidized beds may be experiencing severe gas bypassing even though lab- and pilot-scale studies indicate otherwise. If the bed height and the emulsion phase density are high enough, gas will compress and cause the bulk of the bed to defluidized. This results in a bed instability that propagates to gas bypassing, jet streaming, or channeling. Studies at PSRI have found that gas streaming is dependent on several factors such as bed height, gas velocity, fines level, and baffle design. In addition, Barracuda™ simulations confirmed the role of fines with respect to the onset of gas bypassing.

For a commercial unit experiencing gas bypassing, the best remedy may be to increase the fines level or add horizontal baffles at the proper spacing. Lowering the bed height or increasing the gas velocity will also remedy the problem, but this tends to be more problematic for industrial plants.

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