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UNDERSTANDING STANDPIPE HYDRODYNAMICS USING ELECTRICAL CAPACITANCE TOMOGRAPHY

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ABSTRACT

Standpipes are often the bottleneck in a circulating fluidized bed processes. Understanding the pressure build and dissipation in a standpipe is critical in designing and operating a standpipe that can meet production needs. However, this critical component of a circulating fluidized bed (CFB) is often neglected in the design process which usually results in an underperforming unit operation. In an effort to better design new standpipe and to better optimize existing ones, electrical capacitance tomography (ECT) was evaluated in a 7-inch (18-cm) diameter standpipe to understand the gas-solid hydrodynamics in a standpipe with respect to circulation rates and aeration strategies.

INTRODUCTION

Standpipes are the pressure balance in a circulating fluidized beds. It is the pressure build and dissipation in a standpipe that determined the maximum circulation rate or solids flux in a circulating fluidized bed (CFB). How a standpipe is aerate determined the level of pressure build that can be obtained. For Geldart Group A powders, uniform aeration is recommended. For Geldart Group B powders, only aeration near the slide valve is recommended [1]. Even the level of aeration should be considered as an important operating parameter [2]. Too much, and the bubbles can defeat any possible pressure build and too little makes the aeration ineffective.

Yet, how aeration enhances the standpipe pressure build is unclear. Does the aeration provide a reduction in friction at the wall or does the gas penetration deep into the standpipe and keeps the solids fluidized or perhaps both? To better understand how aeration effects solids hydrodynamics in a standpipe, electrical capacitance tomography (ECT) was installed on an 7-inch (18-cm) diameter standpipe of circulating fluidized bed cold-flow unit.

EXPERIMENTAL

Standpipe

Tests were conducted in a 8-inch (20-cm) diameter circulating fluidized bed equipped with a 8-inch (20-cm) diameter standpipe and a 7-inch (18-cm) diameter spool piece for the ECT electrodes, as shown in Figure 1. The riser was 22-m tall and terminated with an elbow with an r/D of 1.5 to a 48-cm diameter primary cyclone, a secondary cyclone, and diplegs to route the solids collected by the cyclones into the 3-ft (0.9-m) diameter fluidized storage hopper. A 20-cm diameter by 16.8-m tall standpipe returns the solids back to the riser. A 7-inch (18-cm) diameter spool piece was incorporated into the riser near the slide valve to accommodate the ECT system. A diverter valve in the first-stage cyclone dipleg allows solids to be diverted into a collection hopper on load cells so that the solids flow rate can be measured.

The facility operated at ambient temperature and pressure. It can operate at gas velocities of up to 70 ft/s (21.3 m/s) and at solids fluxes in the riser of 200 lb/s-ft^2 (980 kg/s-m^2). The unit was filled with equilibrium FCC catalyst powder having a particle density of 1500 lb/ft^3 and median particle size of 72 microns.

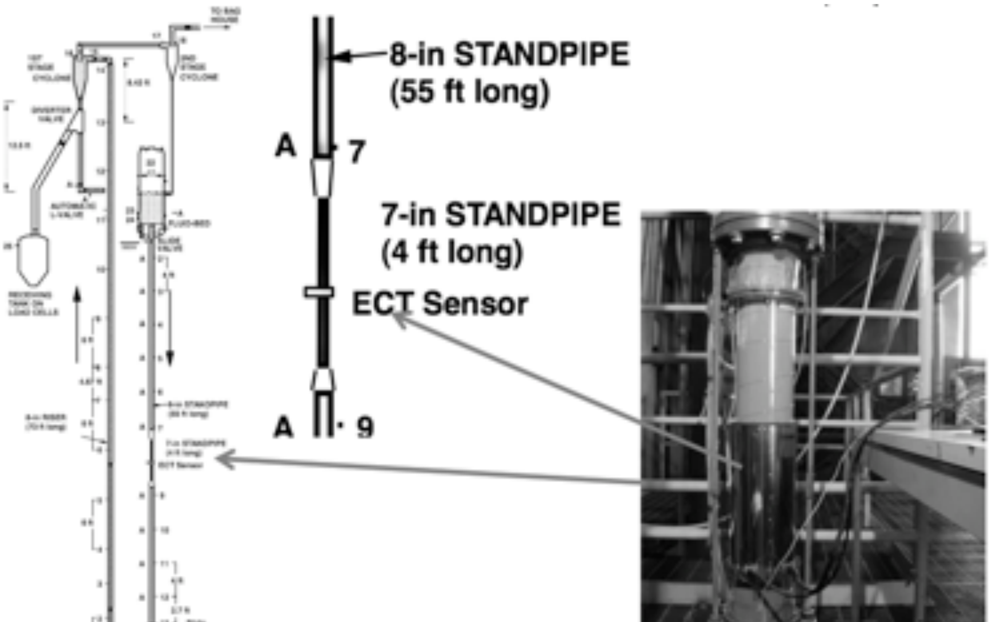

Figure 1: Schematic and picture of 8-inch (20-cm) diameter CFB with 7-inch (18-cm) diameter spool piece for ECT system.

Two trials were conducted, the first test was to establish optimal measurement parameters; the second was to observe and evaluate the ECT system over a test matrix of 16 fluidized beds flowing process conditions. These conditions are presented in Table 1.

Table 1: Experimental design for ECT evaluation in a 7-inch (18-cm) diameter standpipe.

Test Case	Solids Flux		Aeration Rate		Aeration Injection Points
	lb/ft^2-sec	kg/m^2-sec	SCFH	SCMH	
1	0	0	30	0.850	All
2	0	0	50	1.416	All
3	5	24	25	0.708	All
4	5	24	20	0.566	All
5	10	49	15	0.425	All
6	28	137	20	0.566	All
7	28	137	20	0.566	All but Increasing Qg from 20-200 @ #9,#10
8	60	294	30	0.850	All
9	50	245	35	0.991	All
10	50	245	40	1.133	All but Qg @ #9 increasing from 40 to 200
11	76	372	35	0.991	All
12	76	372	35	0.991	All but Increasing Qg from 35 up to 200 @ #7,#9
13	115	563	35	0.991	All
14	115	563	35	0.991	All but Increasing Qg from 35 up to 200 @ #7
15	115	563	200	5.664	All
16	115	563	200	5.664	All but decreasing the Qg from 200 down to 40@ #7

Electrical Capacitance Tomography

The tests were performed using an ITS m3000c Electrical Capacitance Tomography system (ECT). The instrument operates by taking measurements from the multiple electrodes arranged around a pipe to obtain information on the material(s) within the pipe by dielectric imaging.

The ITS capacitance sensor was 7-inch (18-cm) internal diameter with 12 electrodes, the PSRI fluidized bed circulation pipe at either side (top and bottom) was 8-inch (20-cm) diameter. It driven by an m3000c system, - which applies a voltage to an electrode and measures voltages between this and all other electrodes. Measurements are repeated rapidly (in approx. 20 ms) until all combinations have been measured for a single frame of data. Overall, 66 capacitance measurements points are taken per frame. These are combined using proprietary software to provide a cross-sectional map of the capacitance distribution through the pipeline. Including on line image processing data is presented at 12 Hz.

The measurements are very sensitive (measuring capacitances in order of pico-Farads). To ensure data is collected properly high and low thresholds must be taken with homogeneous material in the sensor. After a number of tests (calibrations), it was determined that the optimal threshold settings were: the low reference with the gas filled into the sensor and high reference with the fully packed FCC catalytic power filled with the sensor during the real time trial tests.

RESULTS AND DISCUSSION

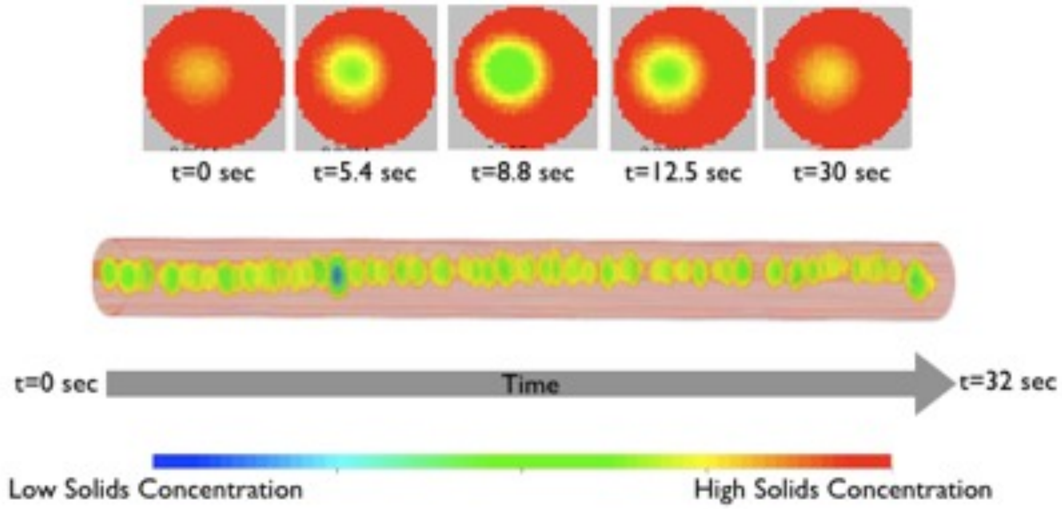

Figure 2: ECT scans for a standpipe at rest with uniform aeration and the slide valve fully closed (Test Case 1).

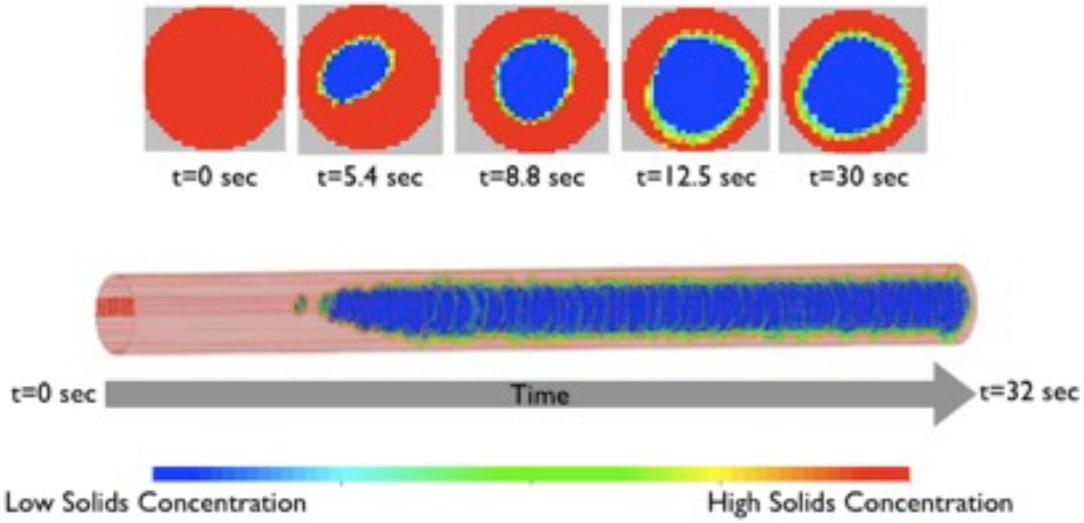

Figure 3: ECT scans for a standpipe at a solids flux of 76 lb/ft^2-sec (385 kg/m^2-sec) with 35 SCFH (0.991 SCMH) uniform aeration and the slide valve at the 0.5-inch (1.25-cm) opening position (Test Case 3).

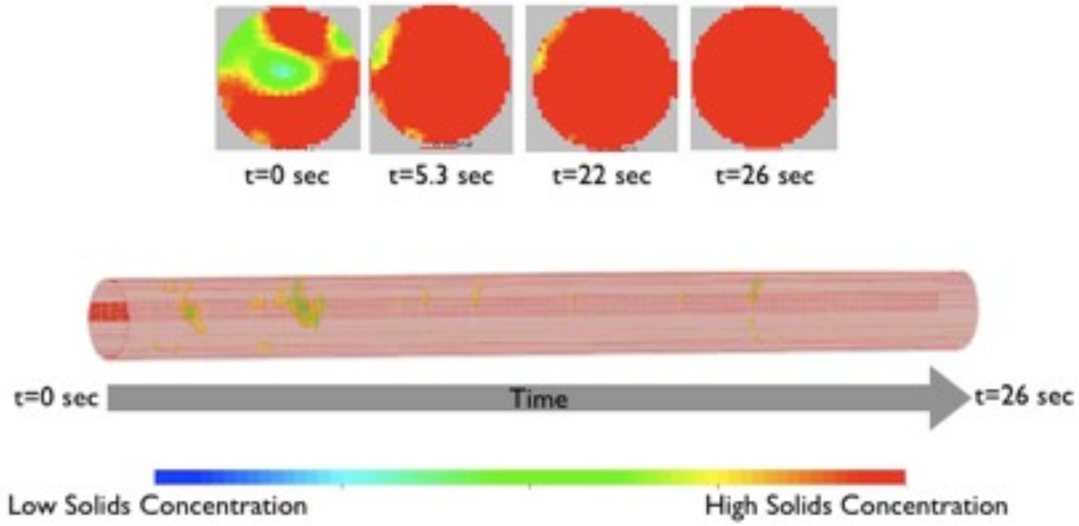

Figure 4: ECT scans for a standpipe at a solids flux of 115 lb/ft^2-sec (563 kg/m^2-sec) with 200 SCFH (5.7 SCMH) uniform aeration and the slide valve at the 1.9-inch (4.8-cm) opening position (Test Case 15).

Figure 2 shows the results of the ECT scan for a 7-inch (18-cm) diameter riser at a zero solids flux (slide valve was fully closed) with 25 SCFH (0.71 SCMH) uniform aeration, which corresponds to Test Case 1. Under these conditions, the standpipe behaved more like a bubbling fluidized bed. The ECT scans started with the startup of the aeration. The images are plotted on a 32 x 32 grid with 820 pixels within the circular geometry of the sensor. The lower image of Figure 2, shows 3D tomographic images in a 'stack' of 400 images. This represents a time period of 32 seconds and allows temporal flow features to be observed over this time period. The ECT scans revealed the expected behavior for a bubbling fluidized bed. Gas bubbles were clearly resolved in the center of the standpipe with respect to time.

Figure 3 shows the ECT scans for an operating standpipe at a solids flux of 76 lb/ft^2-sec (385 kg/m^2-sec) with 35 SCFH (0.991 SCMH) uniform aeration, which corresponds to Test Case 11. For the results shown in Figure 3, the ECT scans started with the startup of the standpipe and the aeration. During the next 30 seconds, gas from the aeration ports appeared to from a core-annulus profile with low concentrations of solids in the center of the standpipe.8

This was an expected profile determined by the ECT scans. The slide valve position for this test case had only 0.5-inch (1.25-cm) opening and was the limiting factor for the solids circulation rate. The amount of aeration far exceeded that needed to enhance the standpipe flow. This resulted in the generation large pockets of gas flowing up the standpipe.

Opening the slide valve such that it no longer limited the flow, changed the gas-solid distribution completely, as shown in Figure 4. With the slide valve opened to the 1.9-inch (4.8-cm) position, solids fluxes increased to 115 lb/ft^2-sec (563 lb/m^2-sec). As shown in Figure 4, the aeration gas quickly migrated to the wall, even with the aeration increased to 200 SCFH (5.7 SCMH).

Thus, it appears that at low solids flow rates in standpipes, bubbles have enough momentum to push the solids to the wall and generate a core-annulus profile. At

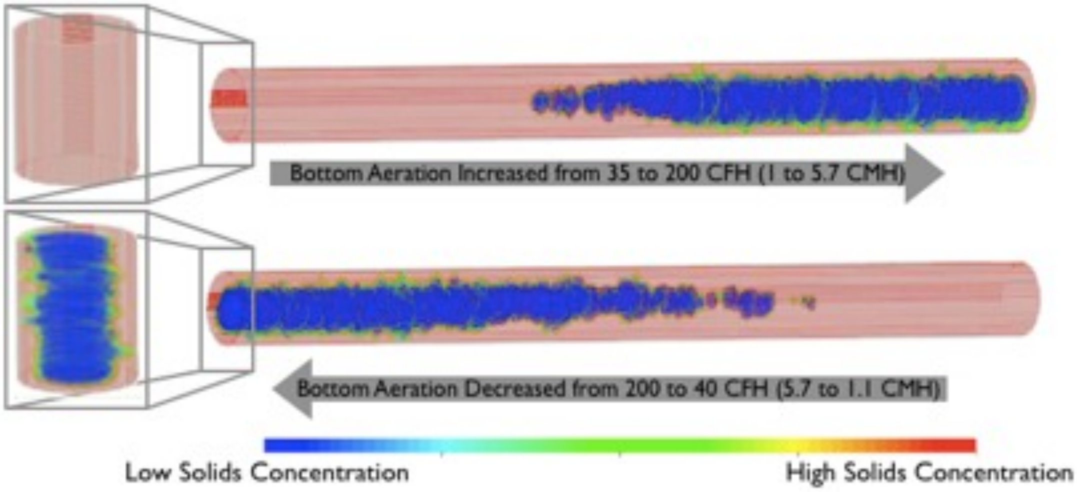

Figure 5: ECT scans for a standpipe at a starting solids flux of 115 lb/ft^2-sec (563 kg/m^2-sec) with 35 to 200 SCFH (1 to 5.7 SCMH) bottom aeration (Top - Test Case 14) and 200 to 40 SCFH (5.7 to 1.1 SCMH) bottom aeration (Bottom - Test Case 16)and the slide valve at the 1.9-inch (4.8-cm) opening position.

high solids flows, the solids momentum restricts the gas to the walls. In this mode, it is suspected that the gas may act as a lubricant against the solids shear stress and friction at the wall and thereby further enhance the standpipe flow and pressure build. These results are consistent with earlier ECT studies done in a 3-inch (4.6-cm) diameter standpipe [2]. In addition, PETP studies in a 1-inch and 3-inch (2.5-cm and 4.5-cm) diameter standpipe by Chan et. al. [3] that with good standpipe operation, the solids flow seemed to dominate the center of the riser as well. They also noted that velocity distribution of solids is asymmetrical within the standpipes cross-section with a faster motion away from the aeration point but a slower motion closer to the aeration point.

Where the aeration comes into the standpipe is equally important. For Geldart Group A powders, uniform aeration is recommended where as for Geldart Group B powders, only aeration near the slide valve is recommended [1]. As shown in Figure 5, increasing gas flow from 35 to 200 SCFH (1 to 5.7 SCMH) in only one aeration port at the bottom of the standpipe resulted in flow instabilities in the standpipe aeration despite that similar, relatively high levels of aeration were deemed useful for Test Case 15 shown in Figure 3 for uniform aeartion. Stability was regained when the aeration was lowered to 40 SCFH (1.1 SCMH). The contrast between the ECT scanned images between Figures 4 and 5 suggest that for Geldart Group A powders, too much aeration in one location could lead to a core-annulus profile with low solids concentration in the center of the riser, indicative of unstable standpipe flow.

CONCLUSIONS

ECT imaging of standpipes appeared to generate expected results and highlighted the role aeration has on standpipe behavior. Too much aeration or aeration in the wrong position can lead to the gas migrating to the center of the standpipe and impede solids circulation rates, and standpipe pressure builds. Well positioned aeration and the correct levels results in the gas migrating to the wall region and perhaps reduce solids stress and friction at the wall, which enhances the solids circulation rates.

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