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Allan Issangya
Particulate Solid Research, Inc., USA

Reddy Karri Dr
P.S.R.I., reddy.karri@psrichicago.com

Ted Knowlton
Particulate Solid Research, Inc., USA

Ray Cocco
Particulate Solid Research, Inc., ray.cocco@psrichicago.com

EFFECT OF GAS BYPASSING IN DEEP BEDS ON CYCLONE DIPLEG OPERATION

A. S. Issangya, S. B. Reddy Karri, Ted M. Knowlton and Ray Cocco
Particulate Solid Research, Inc., 4201 W 36th Street, Suite 200, Chicago, USA

ABSTRACT

Cyclone diplegs play a major role in the functioning of fluidized beds. Previous studies have shown that at certain operating conditions there can be severe gas bypassing (also referred to as jet streaming) of gas in deep beds of Geldart Group A materials which leaves significant portions of the fluid bed defluidized. If cyclone diplegs are immersed in these defluidized regions, solids discharge from the dipleg may be hindered, which can lead to the flooding of the dipleg and the cyclone. This could result in high solids losses from the fluidized bed. Tests were conducted to demonstrate that cyclone diplegs can flood when discharging into a bed with gas bypassing. Tests were also conducted to determine how gas bypassing affects the operation of cyclone diplegs that have a splash plate or a trickle valve. These tests were conducted in a 1.52-m-diameter semicircular column equipped with a Plexiglas faceplate to allow visual observation.

INTRODUCTION

Cyclone diplegs are pipes attached to the conical bottom of cyclones that return the collected solids back into the system. Cyclones are widely used in catalytic processing units where diplegs are used to return collected catalyst particles back to fluidized beds. Diplegs can discharge solids above a fluid bed (suspended diplegs) or directly into the fluid bed (submerged diplegs). During start-up, the fluidizing gas preferentially flows up the dipleg of a second-stage cyclone until a solids level in the dipleg is established to seal it. First-stage cyclone diplegs generally have enough solids flow through them to allow a seal to be established in spite of the initial upward gas flow in the dipleg, and sealing devices at the dipleg exit of first stage cyclones are typically not necessary. Splash plates, placed a short distance below the dipleg, are often been used with first stage diplegs to try to prevent gas from entering the dipleg. The solids flow rate in second stage cyclones is generally too small to establish a seal unless a device such as a trickle valve is attached to the dipleg end to prevent gas from flowing up the dipleg.

Despite the wide use of cyclones and diplegs in fluidized beds, there are only a few dipleg studies in the open literature. Bristow and Shingles (1) identified four operating modes of trickle valves in diplegs: trickling, dumping, trickling/dumping, and flooding. Flooding occurs if the solids flow into the dipleg is greater than the solids being discharged from the dipleg causing the dipleg to fill with solids and back-up into the cyclone. A blowing mode can also occur in some cyclone diplegs

(2) where the pressure inside the cyclone can be greater than at the end of the dipleg.

Geldart et al. (3) found that a considerable amount of the cyclone inlet gas can be dragged downwards by the solids if the dipleg is operating in streaming flow. Dries and Bouma (4) proposed five modes of flow in a cyclone dipleg; (a) stick-slip flow when the solids in the dipleg were in packed bed condition, (b) transition flow mode in which the dipleg had a dense fluidized region on top of a packed bed region, (c) unstable flow at low solids fluxes, and (d & e) at higher solids fluxes, a wholly dilute phase flow or a dipleg flow with a dilute region on top of a dense fluidized region. Wang et al (5, 6) measured axial pressure and radial solids volume fractions and particle velocity profiles in cyclone diplegs and the amount of gas flowing down the dipleg. The formation of a dense phase in a dipleg was found to significantly decrease the amount of gas downflow.

Karri and Knowlton (2) found for FCC catalyst that aeration substantially increased the amount of solids flow through both immersed and nonimmersed trickle valves and that the solids flux through the dipleg was not a function of the flapper weight when aeration was used. The best aeration locations for a trickle valve were found to be just above the mitered bend and at the midpoint of the mitered section. It was also found that cyclone gas was dragged down the dipleg into the bed by the fast moving solids when the solids flux exceeded about 100 kg/ s-m^2.

One factor that is missing in submerged dipleg studies is how solids discharge from a dipleg is affected by the quality of fluidization at the point of discharge. Studies (Wells, 7; Knowlton, 8; Karri et al., 9; Issangya et al., 10, 11; Karimipour and Pugsley, 12) have shown that deep beds of Geldart Group A materials can have defluidized regions caused by gas bypassing. Most of the fluidizing gas was observed to preferentially flow up near the column wall in a single or a number of high velocity streams of bubbles. Gas bypassing was attributed to decreased voidage and permeability of the emulsion phase due to the compression of gas in the emulsion phase caused by the pressure head developed in deep beds. Bolthrunis (13) found that severe gas maldistribution occurring in a large fluid bed reactor could be prevented by installing baffles.

If cyclone diplegs are located in the poorly fluidized region of a gas bypassing bed, solids discharge from the dipleg will likely be hindered, which can lead to the flooding of the dipleg and the cyclone. Defluidization can also result from poorly designed or defective gas distributors. This paper discusses tests conducted to determine if cyclone diplegs with and with no exit attachments will flood because of gas bypassing in the fluid bed.

EXPERIMENTAL

Tests were conducted in a 1.52-m-diameter, 5.2 m tall semicircular fluidized bed that had a Plexiglas faceplate (Figure 1). The unit had three, 41-cm-diameter, tangential inlet internal first stage cyclones (Figure 2). The left and the right hand side cyclones had 15-cm-diameter fully round diplegs that discharged solids into the bed 25 cm away from the faceplate. The middle cyclone had the test dipleg which was transparent and semicircular and was attached to the flat faceplate to enable visual observation of solids flow through it. Air exiting the three primary cyclones entered a

51-cm-diameter second stage cyclone and then passed into a third stage cyclone of the same diameter before entering the exhaust header. The third stage cyclone dipleg returned solids to the second-stage cyclone dipleg via an automatic L-valve and the combined flow was returned to the column by another automatic L-valve.

The operation of the middle cyclone dipleg was studied for various solids fluxes through the dipleg, and with and without dipleg aeration. In order to have a wide range of solids fluxes through the test dipleg, diplegs of two sizes, 7.6 and 20 cm diameters, were tested. The solids flux was also varied by changing the bed superficial gas velocity. The solids flux through each dipleg was calculated from the measured fluid bed entrainment rate at a given superficial gas velocity by assuming that the loading was split equally among the three cyclones.

At superficial bed velocity of 0.9 m/s, the solids fluxes in the 15-cm-diameter round dipleg and the 20-cm-diameter semicircular dipleg were 85 and 96 kg/s-m^2, respectively. These values are within the high solids flux range of commercial second stage diplegs which are normally operated at fluxes much less than 100 kg/s-m^2. The solids flux in the 7.6-cm-dia. semicircular dipleg was 684 kg/s-m^2 at the same gas velocity in the bed. This was within the range of the solids fluxes in commercial first stage cyclone diplegs which are typically 350 to 750 kg/s-m^2.

The Plexiglas faceplate allowed visual observation of the quality of fluidization in the bed and of the flow of solids and bubbles in the diplegs. Digital videos of the dipleg flow were made at selected operating conditions. Differential pressure (ΔP) fluctuations were measured across bed axial lengths of 60 cm at five locations around the circumference of the unit. The ΔP fluctuation data offered another way of assessing if there was gas bypassing in the bed. Locations near the gas bypass stream have been found (Issangya et al. (3)) to have significantly higher ΔP fluctuations than the rest of the bed.

The middle cyclone dipleg was tested having (a) no exit terminations (b) a trickle valve and (c) a splash plate (Figure 3). The two 15-cm-diameter interior cyclone diplegs had no exit attachments. The splash plate tests were conducted with the 7.6-cm-diameter dipleg where high solids fluxes, typical of those in primary cyclone diplegs, could be achieved. An 8.9-cm-diameter semicircular steel splash plate was placed 8.9 cm below the dipleg end. The distance of the splash plate from the dipleg end was calculated such that the solids discharge area was twice the area of the open end of the dipleg, a criterion often used in industry.

The trickle valve tests were conducted with the 20-cm-diameter dipleg. The trickle valve was made from a 15-cm-diameter pipe whose opening was inclined 4 degrees from the vertical. The trickle valve flapper plate was attached to the pipe by loose hanger rings.

The cyclone diplegs were operated both without and with dipleg aeration. The dipleg aeration was equivalent to a gas velocity of 0.03 m/s in the dipleg. The aeration for the diplegs with no exit terminations and the one with a splash plate were located 2.54 cm above the open end. Aeration was supplied to the dipleg with a trickle valve 15.2 cm above the bend and at the midpoint of the underside of the inclined part of the trickle valve as recommended by Karri and Knowlton (4).

Tests were conducted with two static bed heights: 1.52 m, referenced to the air distributor, to obtain strong gas bypassing in the bed, and 1.07 m to obtain a uniformly fluidized bed. The test material was a 2.5% fines (<44 μm) FCC catalyst with a median particle diameter (dp_{50}) of 85 microns and particle density of 1488 kg/m^3. The particle size distribution is given in Figure 4.

RESULTS AND DISCUSSION

Gas bypassing in the semicircular unit occurred in the form of two gas bypass streams located near the corners where the flat faceplate met the semicircular column. The two streams occasionally moved toward the center of the faceplate or moved inward and around the unit along the wall. Because the shell of the column was made of steel, the motion of the gas bypass stream was only detected from the ΔP fluctuation signals. It was possible to visually observe solids and bubble flow in and around the test cyclone located at the center of the faceplate. Results presented in this study are visual observations of the bed fluidization behavior, and of whether flooding was occurring in the test cyclone dipleg.

Effect on Straight Diplegs With no Exit Attachments

Table 1 shows the results for the 20-cm-diameter semicircular cyclone dipleg with no exit attachment. The fluid bed unit was operated at superficial gas velocities of 0.15 to 0.9 m/s and the static bed height was 1.52 m. The solids flux in the dipleg ranged from 0.24 kg/s-m^2 at a bed velocity of 0.15 m/s to 96 kg/s-m^2 at a bed velocity of 0.9 m/s. With or without dipleg aeration, the dipleg operated well without flooding at all gas velocities. Gas bypassing was present for all gas velocities except at 0.9 m/s where it was significantly reduced because of the high superficial gas velocity. Occasionally, a relatively stagnant dense (but not packed) region formed around the dipleg exit region. This dense region was frequently broken by bubbles rising directly up from the air distributor or by the gas bypass streams that at times moved to the middle of the faceplate. Bubbles rose through the dipleg, but their frequency decreased as the solids flux through the dipleg increased.

Table 1. Dipleg operation: 20-cm-diameter semicircular dipleg (no exit attachment)

Ug m/s	Dipleg Solids Flux kg/s-m^2		Gas Bypassing in the Fluid Bed?	DIPLEG 2 OPERATION	
	Diplegs 1 and 3	Dipleg 2 (D = 20 cm)		No Dipleg Aeration	With Dipleg Aeration
0.15	0.20	0.24	YES	GOOD	GOOD
0.30	1.61	1.95	YES	GOOD	GOOD
0.46	6.35	6.84	YES	GOOD	GOOD
0.61	17.1	19.0	YES	GOOD	GOOD
0.76	36.6	41.0	YES	GOOD	GOOD
0.91	85.4	96.2	WEAK	GOOD	GOOD

Table 2 shows the results for the 7.6-cm-diameter semicircular dipleg with no exit termination for a static bed height of 1.52 m. With no dipleg aeration, the dipleg functioned well for all solids fluxes up to 88 kg/s-m^2. The dipleg flooded for solids fluxes of 103, 137 and 293 kg/s-m^2. At a solids flux of 684 kg/s-m^2 solids bridging occurred in the upper part of the dipleg where there the semicircular dipleg joined the round tube. The solids then accumulated and overflowed into the cyclone. When dipleg aeration was present, the dipleg functioned without flooding at all the solids fluxes except at 684 kg/s-m^2 when bridging occurred. Bubbles were able to rise through the dipleg for solids fluxes up to about 220 kg/s-m^2. The dipleg functioned properly for the 1.07 m static bed tests with or without dipleg aeration except for the highest solids flux that led to dipleg bridging.

Table 2. Dipleg operation: 7.6-cm-diameter semicircular dipleg (no exit attachment)

Ug m/s	Dipleg 2 (D = 7.6 cm) Solids Flux kg/s-m^2	Gas Bypassing in the Fluid Bed?	DIPLEG 2 OPERATION	
			No Dipleg Aeration	With Dipleg Aeration
0.15	1.46	YES	GOOD	GOOD
0.30	13.2	YES	GOOD	GOOD
0.46	48.8	YES	GOOD	GOOD
0.55	87.9	YES	GOOD	GOOD
0.61	136.7	YES	FLOODED	GOOD
0.76	292.9	YES	FLOODED	GOOD
0.91	683.5	NO/WEAK	BRIDGED	BRIDGED

Effect on Diplegs Fitted With a Splash Plate

Table 3 gives the results for the 7.6-cm-diameter semicircular dipleg fitted with a splash plate and with and with no dipleg aeration. With no aeration, the dipleg functioned well for solid fluxes of 13 and 49 kg/s-m^2 but flooded at solid fluxes of 78, 107 and 137 kg/s-m^2. When dipleg aeration was turned on, the dipleg was able to function well at solid fluxes of 107 and 137 kg/s-m^2. Flooding occurred for solid fluxes of 200 and 459 kg/s-m^2 and the dipleg bridged when the solid flux was increased to 684 kg/s-m^2 as was the case was for the straight dipleg discussed above. The dipleg did not flood for tests that were conducted with a static bed height of 1.07 m where no or very weak gas bypassing was occurring. Comparing the dipleg with no attachment with the dipleg with a splash plate under gas bypassing conditions, it appears that with no dipleg aeration a straight open cyclone dipleg worked just as well as the one with a splash plate. However, when there was dipleg aeration the dipleg with a splash plate flooded at a lower solids flux of 200 kg/s-m^2, compared to the straight dipleg which did not flood at Gs = 293 kg/s-m^2.

Effect on Diplegs Fitted With a Trickle Valve

Table 4 presents results for the 20-cm-diameter semicircular dipleg fitted with a trickle valve and with and with no dipleg aeration for a 1.52 m static bed. With no dipleg aeration, the dipleg worked well for solids fluxes of 0.24, 1.92 and 6.83 kg/s-m^2 which corresponded to gas velocities in the bed of 0.15, 1.0 and 0.46 m/s, respectively. The dipleg flooded when the solids flux was raised to 19 kg/s-m^2 corresponding to a bed superficial velocity of 0.6 m/s, but functioned well when the superficial gas velocity was increased to 0.76 m/s. At a superficial gas velocity of 0.76 m/s, the dipleg solids flux was 41 kg/s-m^2. It seemed that more air was able to leak from the bed and enter the dipleg at a superficial gas velocity of 0.76 m/s than at a superficial gas velocity of 0.6 m/s, and this amount of air was sufficient to aerate the dipleg and allow the dipleg to operate without flooding. At a superficial gas velocity of 0.9 m/s, for a solid flux of 96 kg/s-m^2, the dipleg at first flooded but then recovered and continued to function well. Apparently, enough air was able to leak through the trickle valve and reaerate the flooded dipleg. The dipleg flooded at solid fluxes of 130 and 205 kg/s-m^2. These solids fluxes corresponded to superficial gas velocities of 1.0 and 1.1 m/s, respectively. It appeared that even with the higher air leakage from the bed, the solids flux was too high for the dipleg to function without an external supply of aeration. For tests performed with dipleg aeration on the dipleg functioned without flooding at all solids fluxes tested, up to 205 kg/s-m^2.

Table 3. Dipleg operation: 7.6-cm-diameter semicircular dipleg with a splash plate

Ug m/s	Dipleg 2 (D = 7.6 cm) Solids Flux kg/s-m^2	Gas Bypassing in the Fluid Bed?	DIPLEG 2 OPERATION	
			No Dipleg Aeration	With Dipleg Aeration
0.15	1.46	YES	GOOD	GOOD
0.30	13.2	YES	GOOD	GOOD
0.46	48.8	YES	GOOD	GOOD
0.53	78.1	YES	FLOODED	GOOD
0.58	107.4	YES	FLOODED	GOOD
0.61	136.7	YES	FLOODED	GOOD
0.69	200.2	YES	GOOD	FLOODED
0.84	458.9	YES	GOOD	FLOODED
0.91	683.5	NO/WEAK	GOOD	BRIDGED

Table 4. Dipleg operation: 20-cm-diameter semicircular dipleg with a trickle valve

Ug m/s	Dipleg 2 (D = 20 cm) Solids Flux kg/s-m^2	Gas Bypassing in the Fluid Bed?	DIPLEG 2 OPERATION	
			No Dipleg Aeration	With Dipleg Aeration
0.15	0.244	YES	GOOD	GOOD
0.30	1.92	YES	GOOD	GOOD
0.46	6.83	YES	GOOD	GOOD
0.61	19.0	YES	FLOODED	GOOD
0.76	41.0	YES	GOOD	GOOD
0.91	96.2	WEAK	FLOODED THEN RECOVERED	GOOD
0.98	130.3	NO	FLOODED	GOOD
1.07	204.6	NO	FLOODED	GOOD

CONCLUSION

Diplegs immersed in poorly fluidized zones caused by gas bypassing can flood and cause solids to back up into the cyclone causing excessive solids losses. The occurrence of flooding was a function of dipleg solids flux and the presence or absence of a dipleg exit attachment. As found in other studies, dipleg aeration significantly increased the operating range of the dipleg solids flux before flooding would occur. Diplegs with no exit attachments functioned well at all conditions tested if they had dipleg aeration. With no dipleg aeration, diplegs with no exit attachments flooded at solids fluxes of 137 kg/s-m^2 and above. With no dipleg aeration, the dipleg fitted with a splash plate flooded at solids fluxes of 78 kg/s-m^2 and above. The addition of dipleg aeration extended the mass flux operating window of the dipleg. With aeration, the dipleg fitted with a trickle valve functioned well for all conditions tested, up to 205 kg/s-m^2. With no dipleg aeration, the dipleg flooded if the solids flux exceeded 98 kg/s-m^2.

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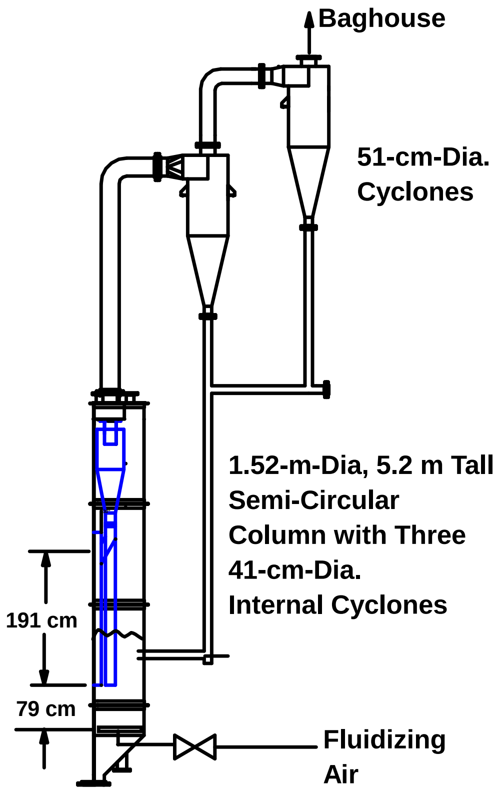

Figure 1. Side View of the Test Unit

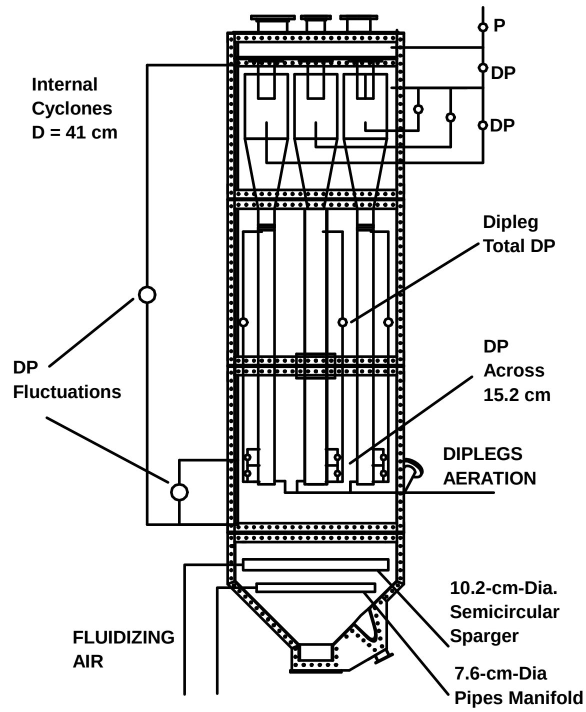

Figure 2. Front View of the Test Unit

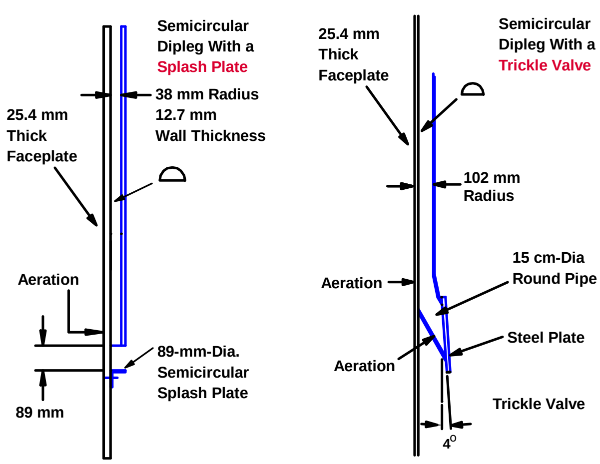

Figure 3. Schematic Drawing of Diplegs with a Splash Plate and a Trickle Valve

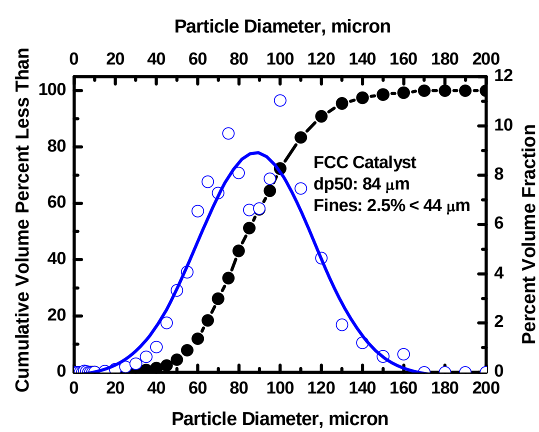

Figure 4. Particle Size Distribution of Material Used