FLUIDIZED BED PROCESS INTENSIFICATION VIA HIGH-G FLOWS

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ABSTRACT

Fluidized beds are used in many industries for their favorable characteristics of good solids mixing, high rates of heat and mass transfer, and large throughputs. In the never-ending challenge of increasing efficiencies one avenue is through process intensification, specifically this work focuses on high-g flows, flows with the centripetal force typically on the order of 10 times the force of gravity. This operating regime provides intensified gas-solids contact through higher mass transfer, heat transfer, gas throughput, and bubble suppression. The design that this work focuses on is a vortexing circulating fluidized bed. This work aims to gain a better understanding of the hydrodynamic forces in these systems through a combination of experimental and modeling efforts.

INTRODUCTION

Improvements in system design, increasing process efficiencies, and reducing overall costs are ever present goals for power generation and many other industrial systems. The design of novel technologies is essential to meeting these constant requirements, and one such avenue in research to achieve these goals is through process intensification. The high mass and heat transfer rates that are possible in fluidized beds make them ideal for employment in many industrial process, including fluid catalytic cracking, gasification, Fisher-Tropsch synthesis, gas purification, and many others (1). One review report examined many of the possible methods for process intensification ranging from operation techniques and bed configuration to the application of external forces and fields (2). This review named swirling gas flow generating techniques as one of the most promising and fertile areas in need of much more fundamental understanding. One area of study that has seen investigation into swirling and vortexing is advanced combustor technology. These studies and others looked into specific systems and examined particle behavior (3) the development of suspension layers (4) and the overall effect of these reactors on process efficiency (5) and pollution control (6). Particle mixing and particle separation are also areas of interest that have seen studies of rotational flows. One such study on mixing developed a bed that would provide near perfect mixing of particle regardless of size difference (7). In the area of rotating or centrifugal systems, studies have shown good agreement between theoretical models to experimental results for the expected pressure drop across the bed (8), examined the effect of gravity on bed expansion (9), and delved into the negatives of partial fluidization (10). Our work in this area will look to expand on these previous studies by characterizing the general hydrodynamics of a vortexing circulating fluidized bed system. This study focuses on the modeling efforts and the preliminary experimental results.

SETUP AND METHODS

NETL designed a cold flow vortexing bed system with dimensions of: 8 inches in diameter and 3 feet in length, with the entrance, exit and recirculation sections 2 inches in diameter. The completed experimental riser is shown in Figure 1. The mass feed is controlled by a variable screw feeder which enters the system through a drop tube. The tangential entrance of the gas flow establishes a rotating flow and generates a vortex which establishes a pressure gradient from the wall to the center. With sufficient volume flow rate a vortexing flow of the particles can be created, with a recirculating flow of solids from the top outer wall of the reactor to the bottom center. There are 14 pressure taps locations along the outer wall to allow for pressure measurements to be recorded by a LabVIEW NI-daq system. Some of these taps will be converted for use as access points for probe measurements of radial pressure distributions, particle volume fraction, and gas velocity. The primary test material is a phosphorescent high density polyethylene(HDPE) with material characteristics listed in Table 2.

Figure 1: Experimental Riser

Modeling of the system was done using Barracuda CFPD software, to determine a working envelope for the system and to provide a baseline for the eventual experimental results to be compared against. Simulations of the vortexing bed system where conducted under following operating conditions: Entrance velocity between 40m/s and 150m/s (6200 LPM-23200 LPM), mass feed of HDPE of 0.005 kg/s, and an atmospheric outlet boundary condition. The lower bound was determined from initial analysis as minimum condition for vortexing flow to be formed. The effect of the mesh was also examined by looking at the effect of grid size and ratio of particle clouds to cells, through the different cases listed in Table 1.

Table 1: Mesh Characteristics

	Number of real cells	# of particle clouds	Ratio of particle clouds to cells	Computation time	Particle feed per average volume
Case 1	14567	3784	0.26	12 days	125
Case 2	6306	759	0.12	6 days	125
Case 3	35334	7065	0.19	21 days	125
Case 4	14567	32013	2.2	16 days	1250
Case 5	14567	132836	9.1	51 days	6000

RESULTS AND DISCUSSION

Figure 2 shows case 1 with three different entrance conditions. In all these instances, there is a vortex flow and recirculation of particles established, however the stability of the flow structure is not consistent. At lower flows, there are some instabilities and cyclic behaviors which can be seen in Figure 3, and as the air flow increases that cyclic behavior is eliminated and a steady state is reached. An increase in the gas flow also allows for steady state to be reached quicker, lowering the overall mass of particles that are in the riser.

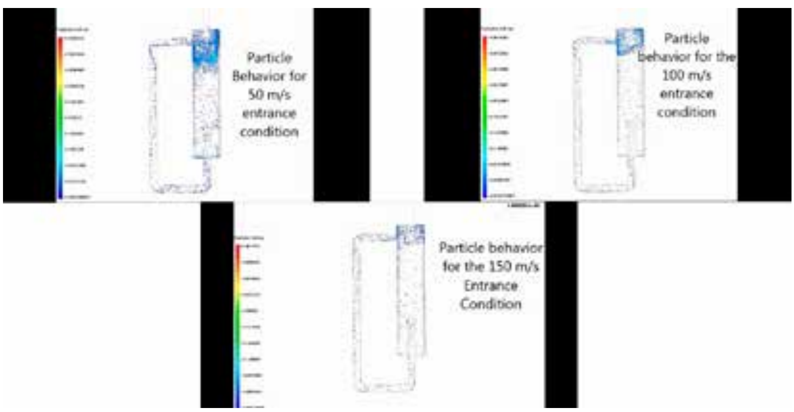


Figure 2: Case 1 at various entrance conditions

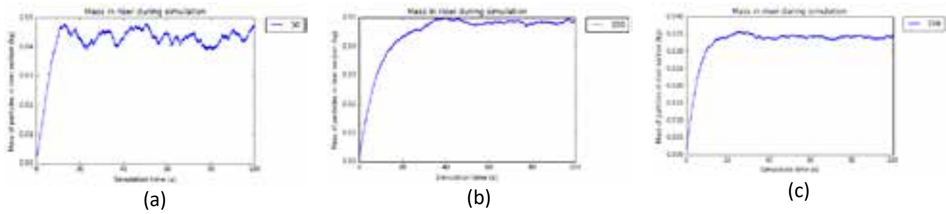


Figure 3:Total mass in riser during simulation

A mesh and computational particle analysis were done to confirm the consistency of the results for case 1 and determine the most computationally efficient model settings. Figure 4 shows a qualitative comparison of the mesh cases 1-3. The fine mesh and medium mesh are consistent in the representation of the flow structure of the particles, while the coarser mesh fails to resolve these same features.

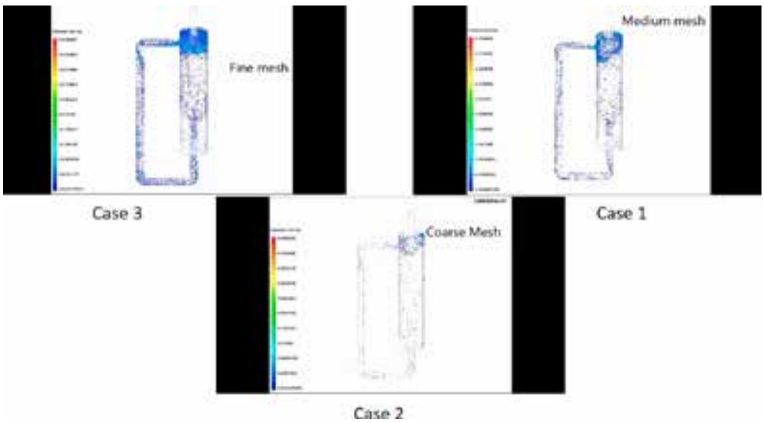
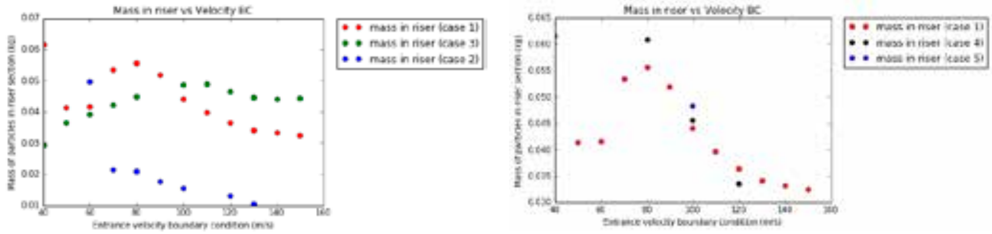


Figure 4: Comparison of grid sizing

Figure 5 (a) shows the mesh comparison over the simulation space. Cases 1 and 3 are in good agreement in the amount of mass in the riser, while the coarse mesh (case 2) falls well below. This is likely due to the coarser mesh failing to fully capture the vortexing behavior that drives the particles to the wall and recirculation section. Without that behavior, more of the solids are just blown out of the riser. Cases 4 and 5 were examining the possible effect of the computational particle cloud density on the results in the simulations. The results of these simulations seen in Figure 5 (b) show strong agreement with the more computationally efficient case 1 with minimal deviation from the initial simulations. The results of the mesh and particle cloud analysis demonstrate that the case 1 settings are the most efficient settings used. The case 1 setting will be used for future simulations and analysis for comparison of experimental results.



(a) (b)

Figure 5: Mesh and Computational Particle comparison

Using the results from case 1, examination of the radial pressure data in Figure 6, shows a linear trend of an increasing radial pressure difference with increasing air flow. The profile of the radial pressure in Figure 7, shows an interesting wall effect that may be due to the presence of particles in the reactor. This effect is seen in the inflection point on the curve, based on previous studies (11), this inflection is not be expected in the pressure profile. Further investigation into the cause of this difference is needed.

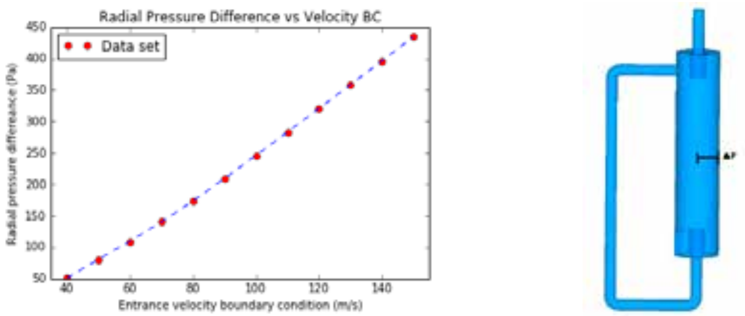


Figure 6: Effect of Entrance condition on Radial pressure difference

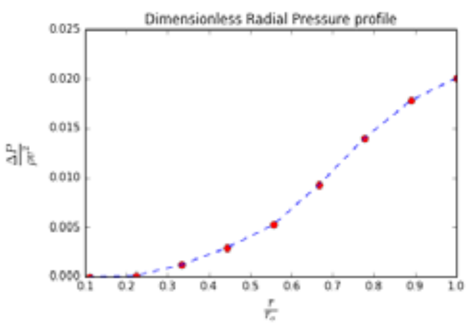


Figure 7: Radial Pressure Profile

Figure 8 shows the results of the axial pressure differential at the various flow conditions. The overall differential is linear with increasing flow rate. Figure 9 shows the profile of the axial pressure, which reveals that most the differential occurs in the bottom 40% of the riser. This height also corresponds with the vortex height, further and more extensive testing is needed to investigate how related the axial pressure profile is to the vortex formation and structure.

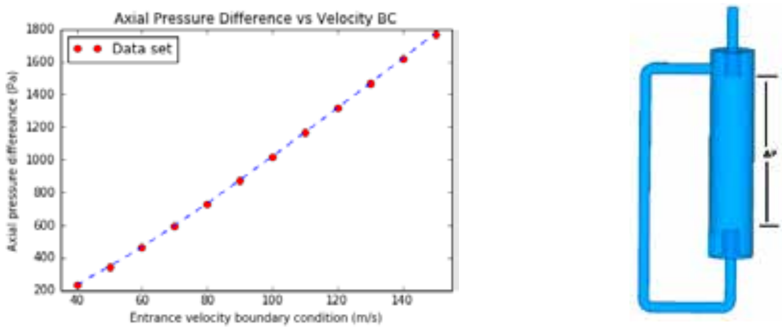


Figure 8: Effect of Entrance Condition on Axial Pressure Difference

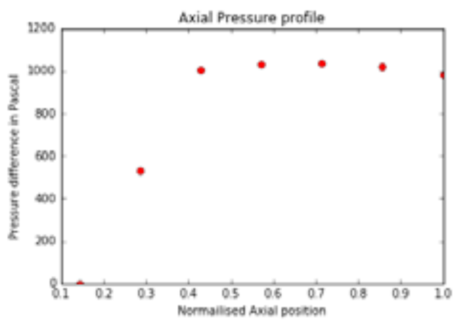


Figure 9: Axial pressure profile

Initial Shakedown of the experimental setup is currently underway. Figure 10 shows a comparison between the simulation and an initial experiment run. Qualitatively the flow structures of the particles are in very good agreement between the two cases. Current issues that are being worked though for the experimental rig are: reduction of static electricity generation, and an inconsistent mass feed. Adjustments to the feed system and introduction of an anti-static additive to the gas flow should eliminate the issues, and allow for full testing to begin. Once the experimental rig is fully operational we plan to validate the current simulation results, and examine the effect of riser dimensions on results, particularly the exit diameter and riser height. We will also look at the effect of particle feed, size, and mixture.

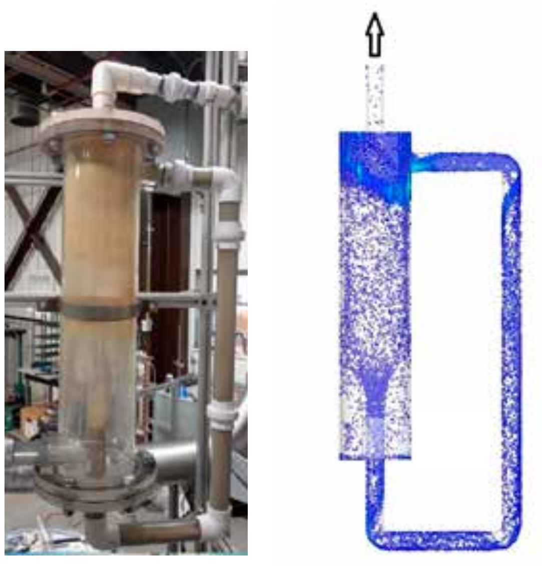


Figure 10: comparison of experimental system to Simulation

Table 2: HDPE material properties

Material		Phosphorescent High Density Polyethylene
Geldart Group		Group B
Particle Diameter, d_p	µm	802
Sauter Mean diameter, d_{sm}	µm	871
Particle Sphericity, ψ_p	-	0.95
Particle Density, ρ_p	kg/m^3	863
Void Fraction Fluffed, ε_f	-	0.410
Void Fraction Nominal, ε_n	-	0.350
Void Fraction Packed, ε_p	-	0.346
Bulk Density Fluffed, $\rho_p(1-\varepsilon_f)$	kg/m^3	509
Bulk Density Packed, $\rho_p(1-\varepsilon_p)$	kg/m^3	564
Minimum Fluidization Velocity, U_{mf}	m/s	0.13
Lower Transport Velocity, U_{tr1}	m/s	4.33
Upper Transport Velocity, U_{tr2}	m/s	6.25
Particle Terminal Velocity, U_t	m/s	2.89

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