Analysis of a Vortexing Circulating Fluidized Bed

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Fluid Particle Science and Engineering

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Projects:

Advanced Reaction Systems

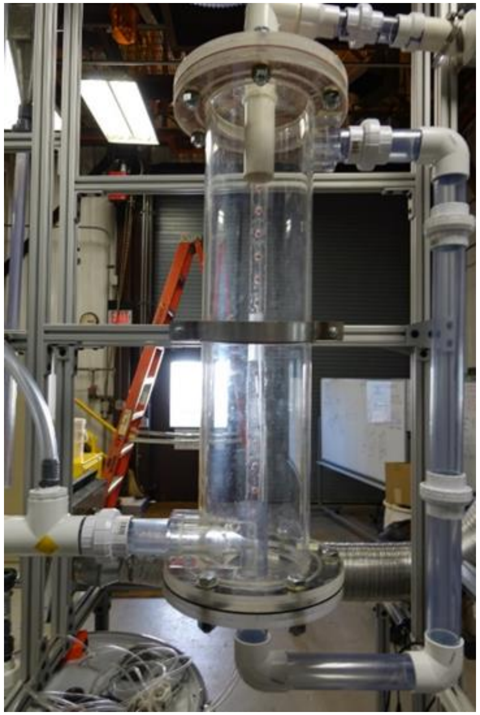
- Rotating Fluidized bed
- Vortexing CFB
- 4-inch cylindrical CFB
- 3x12 inch Rectangular CFB

Advanced Combustion

- Particle separations
  - Bubbling bed
  - Moving bed
  - Spouted bed(s)

Vortexing CFB

- Riser dimensions:
  - 8 inch diameter
  - 3 feet in length
- Gas enters tangentially
  - Cold flow Air
  - Establishes a pressure gradient from the wall to the center
  - With sufficient volume flow rate a vortexing flow of the particles is created
    - recirculating flow of solids from the top outer wall of the reactor to the bottom center



Benefits of Rotating/Vortexing Flows

- Increased particle residences time[1]
- Particles experience different flow regimes[2]
  - Drag forces higher than normal riser
  - Improved particle separation
- For reactive flows[3]
  - Improved heat and mass transport
  - Flame stability
  - Pollutant abatement

Towards Compact Gas/Solid reactors
- Combustion
- Gasification
- Drying

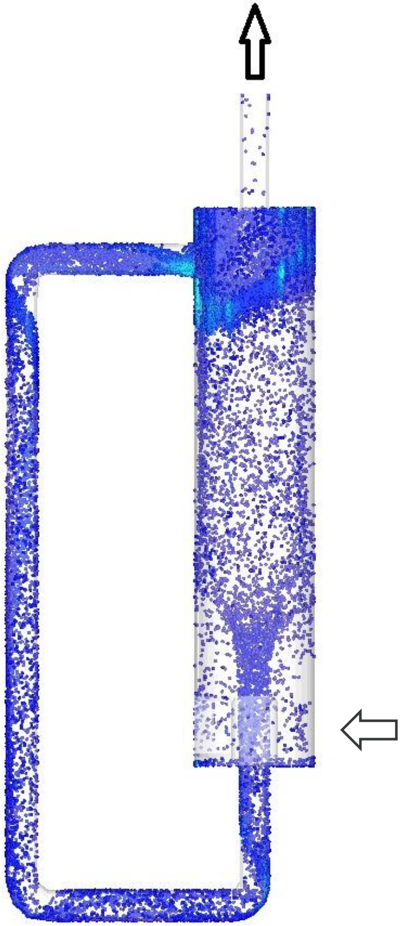
1. Wie Z., "A Review of Techniques for Process intensification of Fluidized Bed Reactors", Chinese Journal of Chemical Engineering, 2009, 688-702
2. J. De Wilde, Gas-solids fluidized beds in vortex chambers, Chem. Eng. & Proc. 85 (2014) 256-290
3. Nieh S., Yang G., Zhu A.Q., Zhao C.S., "Measurements of gas-particle flows and elutriation of an 18 inch i.d. cold vortexing fluidized bed combustion model" Powder technology, 1992, 139-146

Barracuda Simulation

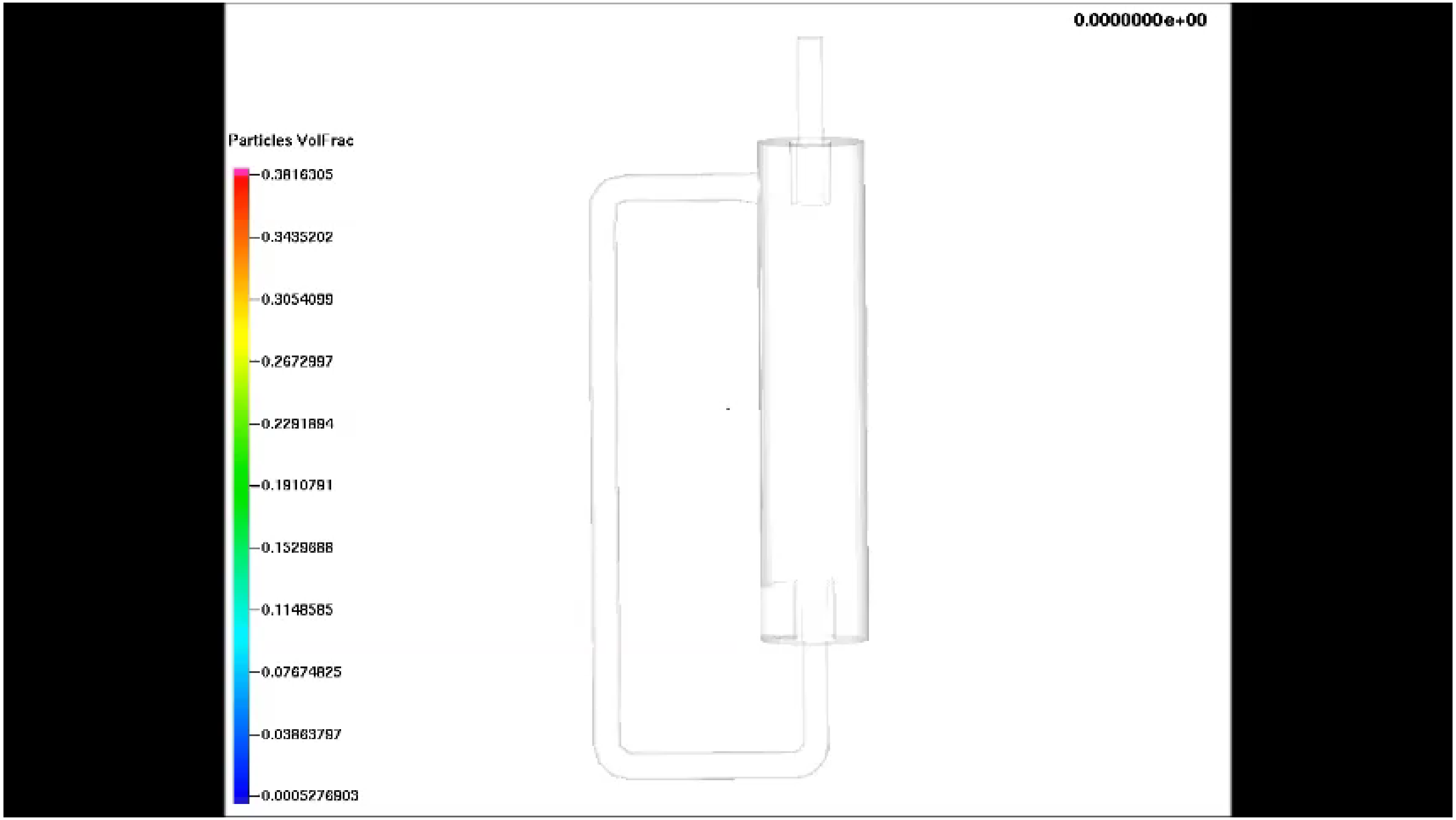
- Establish working envelope for experiment
- Provide a baseline for comparison

Simulations of the Vortexing bed system where conducted under following operating conditions:

- 40 m/s entrance velocity (6200 LPM) to 150 m/s (23200 LPM)
- Entrance feed 0.005 kg/s of HDPE
    - Radius $3x10^{-4}$ m to $5x10^{-4}$ m
- Exit boundary: Atmospheric conditions



Sample Simulation Result



Experimental Test Conditions

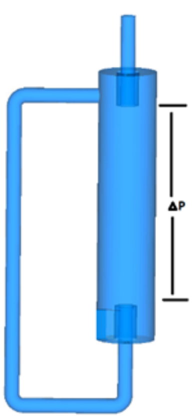
Vortexing CFB operating conditions:

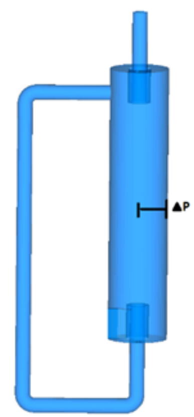
- 55 m/s entrance velocity (7050 LPM) to 83 m/s (10810 LPM)
  - Bounds determined from simulation workspace and experimental system limitations
- Entrance feed 0 - 0.0032 kg/s of HDPE
  - Radius $3x10^{-4}$ m to $5x10^{-4}$ m
- Exit boundary: Atmospheric conditions

	Min	Max
Gas velocity range	7050 LPM	10810 LPM
Entrance gas velocity	54.7 m/s	83.2 m/s
Mass feed	0 kg/s	0.00321 kg/s

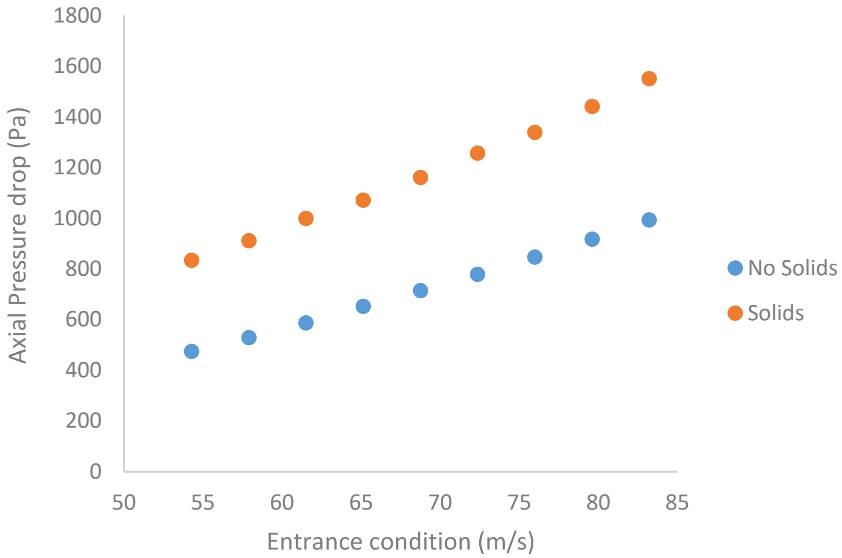
Pressure Mapping

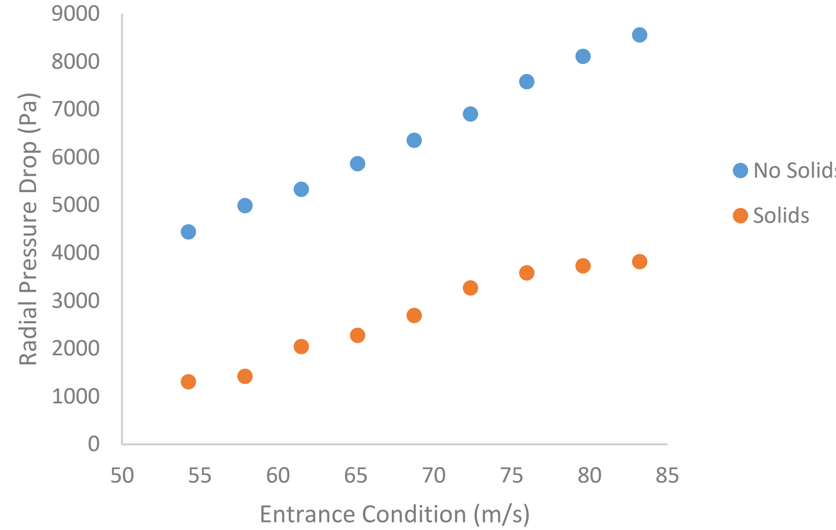
- **Axial pressure was measured at 6 points along the wall**
  - Lowest location was just above the air inlet
  - Highest location was just below the air exit
- **Radial pressure was measured at the middle of the riser**
  - Steel tube 1/8th inch diam.
  - 5 locations between the center and the wall

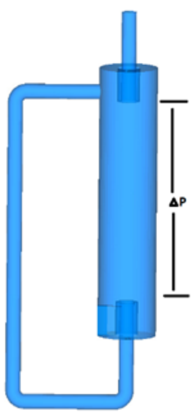


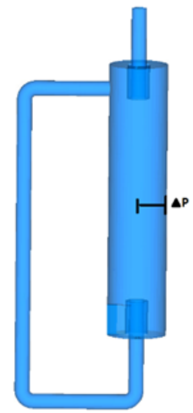


Pressure Mapping









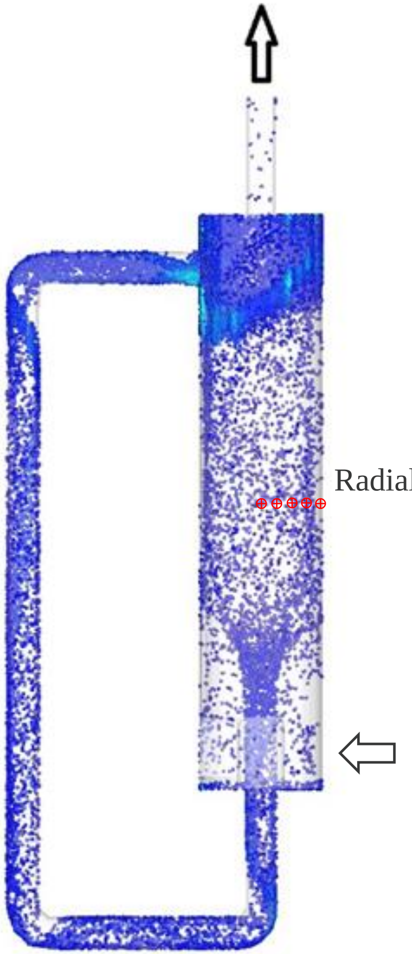
Pressure Mapping

Radial pressure profile

- Radial pressure profile used to determine angular velocities
- Angular velocity used to estimate KE of the gas
- Compare empty system measurements to test conditions

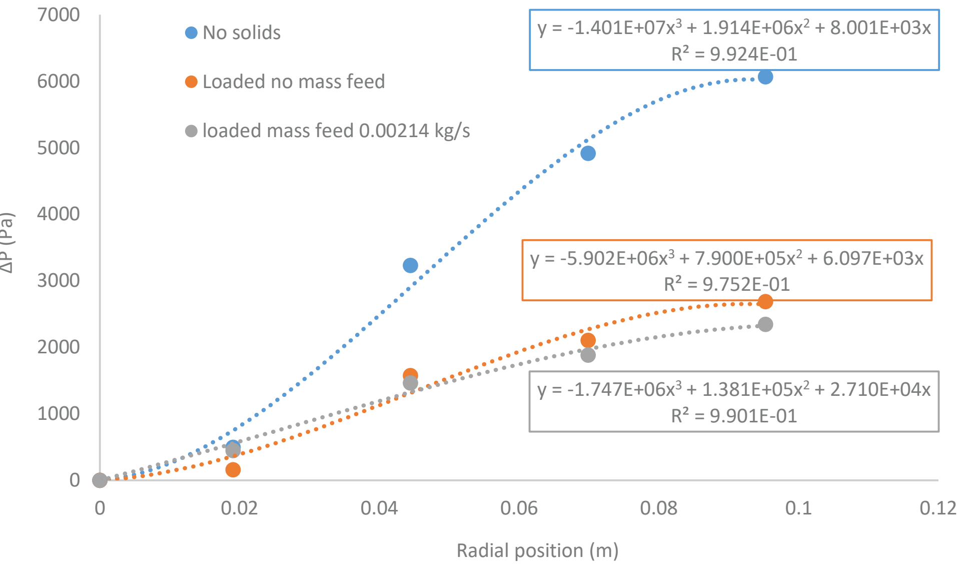
$$\frac{r}{\rho}\frac{\partial P}{\partial r} = w^2$$

$$KE = \frac{1}{2}mv^2$$

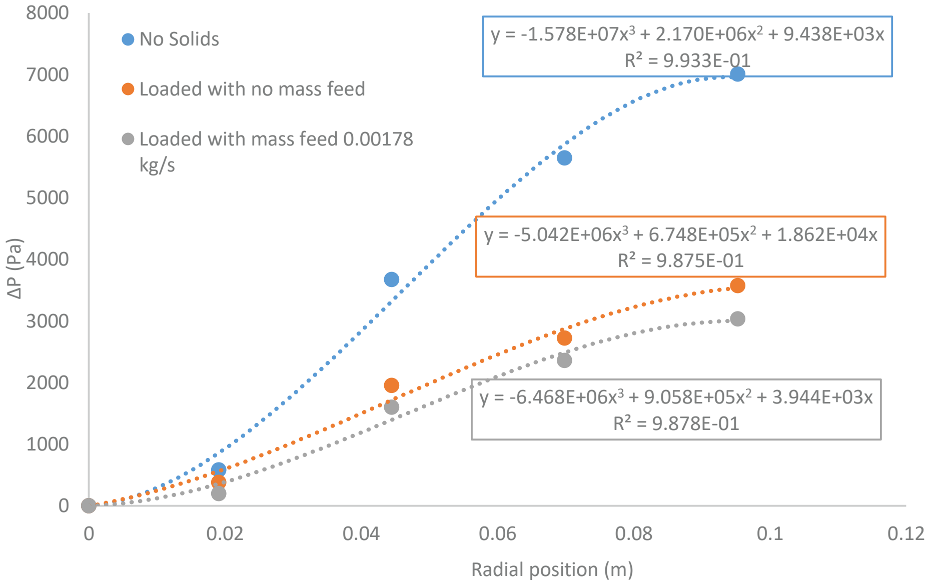


Pressure Mapping

Radial pressure profiles

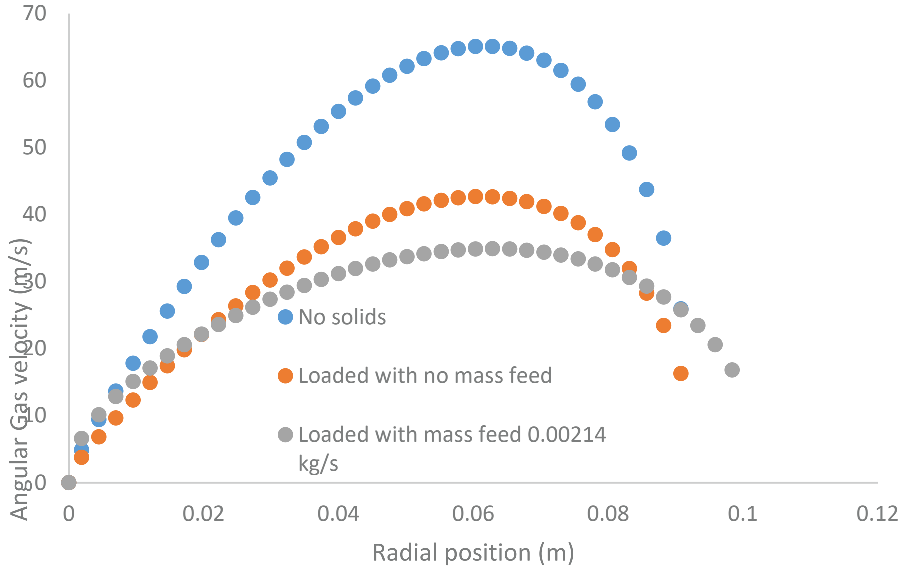


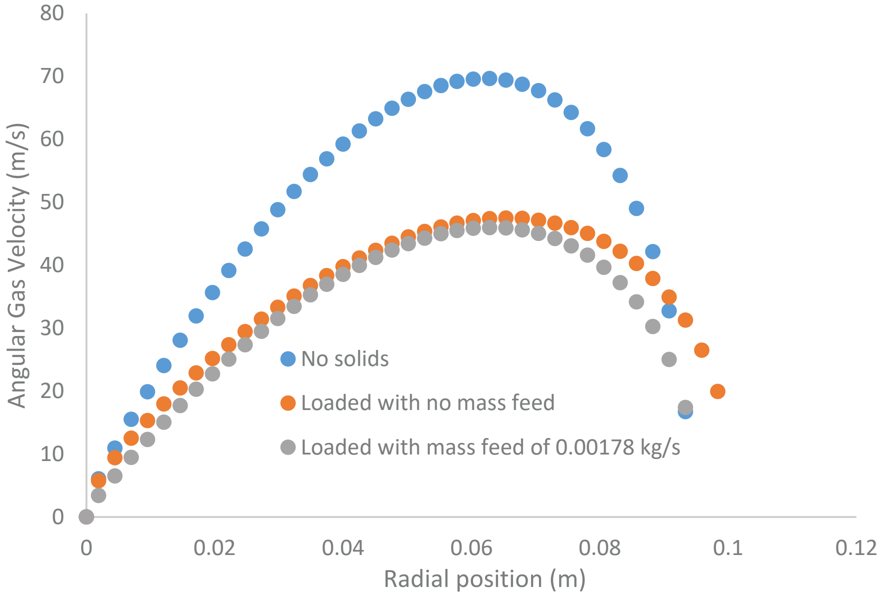
Radial pressure profile for the 68.7 m/s entrance condition



Radial pressure profile for the 76 m/s entrance condition

Radial Velocity Profiles





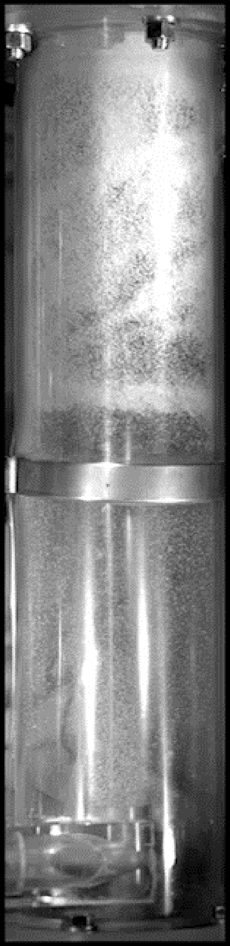
Angular Kinetic Energy

	9870 LPM	8930 LPM
Inlet gas velocity	75.98 m/s	68.75 m/s
Kinetic energy at inlet	98.4 J	80.56 J
KE in gas for EMPTY	51.3 J	43.4 J
KE in gas for Loaded	27.2 J	18.6 J
KE in gas Loaded+feed	22.8 J	15.2 J

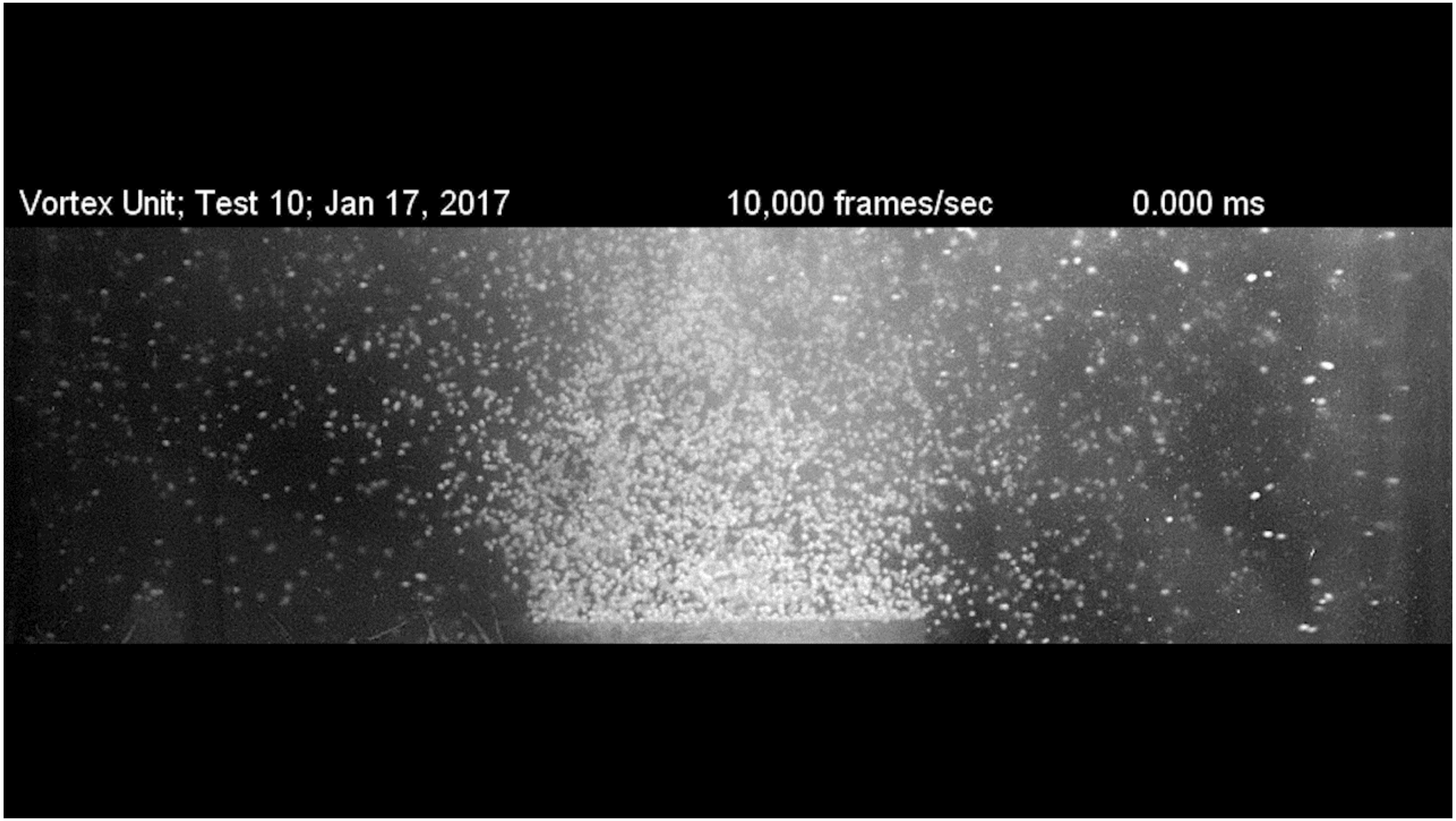
- Difference in energy in gas can be attributed to the addition of particles
  - Energy with known particle velocities can determine mass of particles in the vortexing chamber
  - Energy with known mass can determine velocity of the particles in the vortexing chamber

High Speed Video Particle Tracking

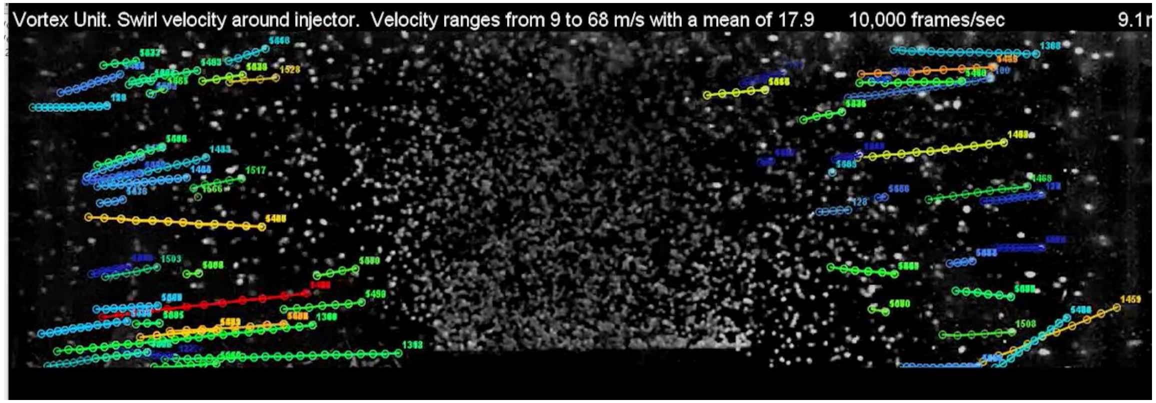
- 20000 SCFH air (72 m/s)
- 2100 Frames/second

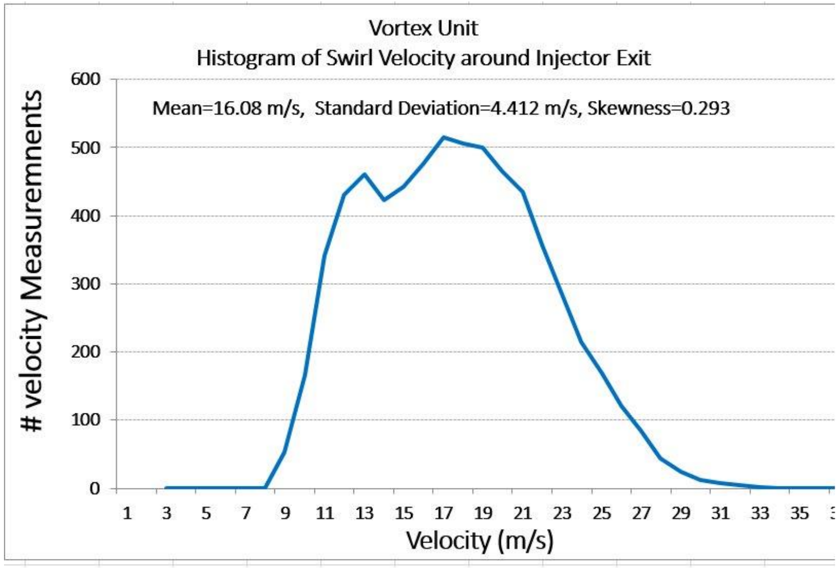


High Speed Video Particle Tracking



High Speed Video Particle Tracking





- Single particle tracking
- Particle Velocity

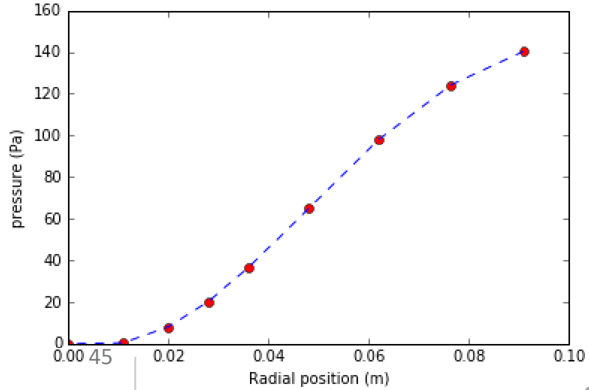
Particle Velocities

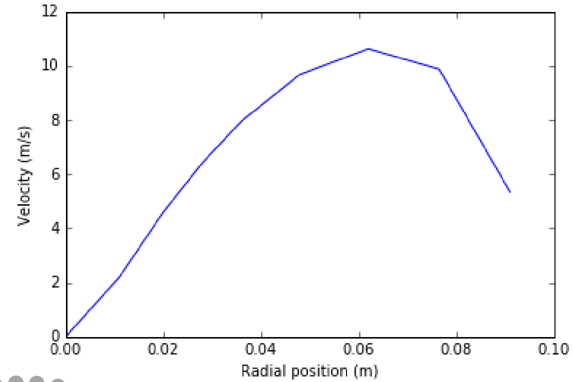
Initial high speed video particle tracking determined particle velocities of roughly 16 m/s

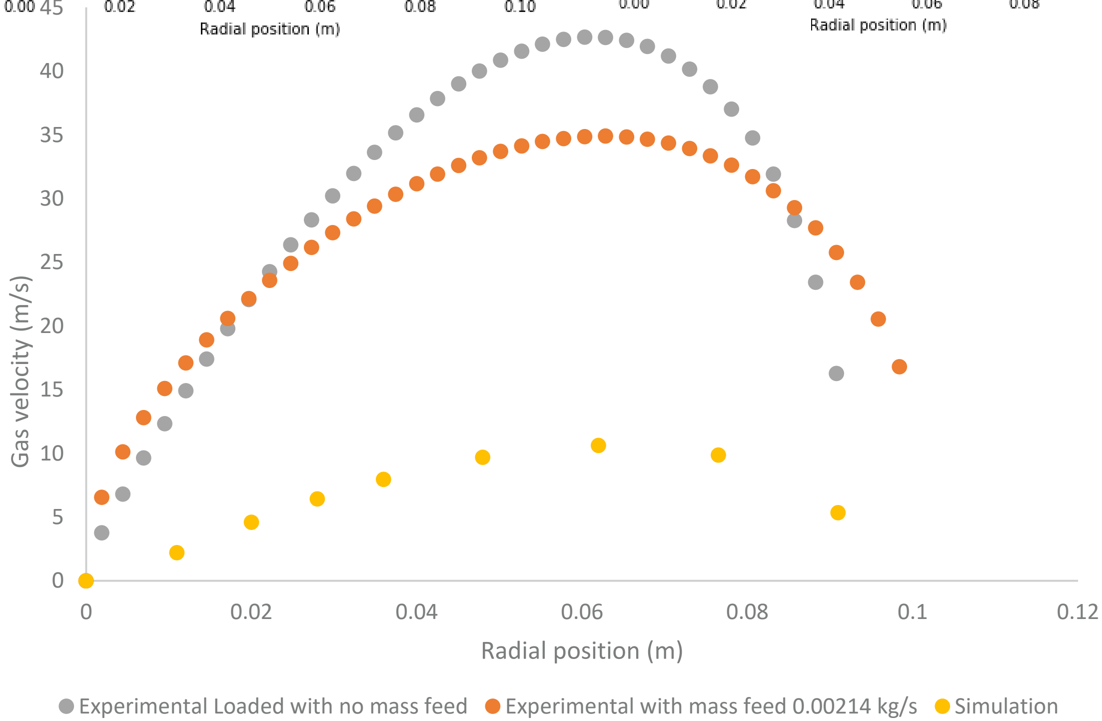
- 72 m/s entrance condition
- Implies roughly 0.22kg of material in the vortex chamber
- Measured weight of particles ~0.3kg in vortex chamber after shutdown
  - ~14 m/s particle velocity

Simulation vs Experimental

Radial Comparison

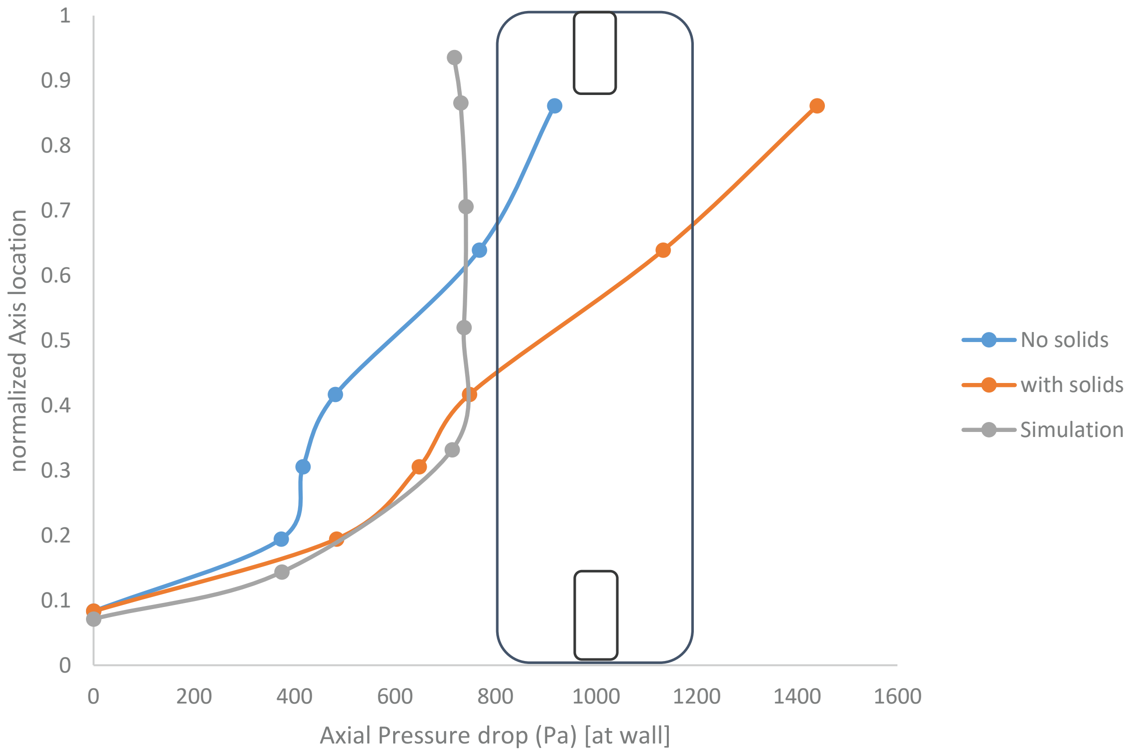


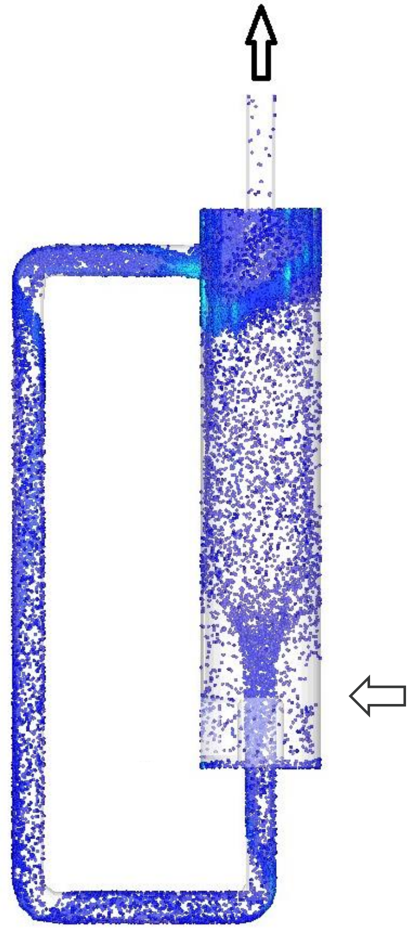




Simulation vs Experimental

Axial Comparison





Simulation vs Experimental

- **Some similarities**
  - Profile shape of radial pressure drop
  - Particle behavior
- **Significant differences**
  - Magnitude of the angular gas velocities
    - Requires finer mesh
  - Axial profile
    - Similar for the lower ~40% of the riser
    - Change occurs near the wall/vortex interface
  - Mass of particles in the riser
    - Lack of vortex trapping in the simulation results in order of magnitude less solids

Future work and next steps

NATIONAL ENERGY TECHNOLOGY LABORATORY

- **Collect more particle tracking data**
- **Determine solids recirculation rate**
  - Frequency analysis
  - Video analysis
- **Examine effect of altering the geometry**
  - Riser height
  - Exit diameter
- **Examine different particles**
  - Density
  - Size
  - Mixtures
- **Adjust simulations to get better agreement with experimental results**
  - Finer mesh
  - Adjust geometry
  - Fine tune initial conditions/boundary conditions