INVESTIGATION OF GAS-SOLID FLUIDIZED BED DYNAMICS WITH NON-SPHERICAL PARTICLES

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Presented by: **Norman Love**

THE UNIVERSITY OF TEXAS AT EL PASO
CENTER FOR SPACE EXPLORATION TECHNOLOGY RESEARCH

Project Participants

- PI: Ahsan Choudhuri
- Co-PI: Norman Love

- Doctoral: Mario Ruvalcaba
- Masters: MD Mahamudur Rahman

Publications and Presentations

CONFERENCE PAPERS

1. Rahman, M., Ruvalcaba, M., Love, N., and Choudhuri, A., "Effect of Bed Diameter, Bed Height and Blockage Ratio on Fluidization in a Gas-Solid Fluidized Bed," 50th *Aerospace Sciences Meeting and Exhibit*, AIAA, Nashville, TN, January 9 – 12, 2012. (Abstract Submitted)

2. Ruvalcaba, M., Rahman, M., Love, N., and Choudhuri, A., "Numerical Study of Gas-Solid Fluidized Bed Dynamics," *50th Aerospace Sciences Meeting and Exhibit*, AIAA, Nashville, TN, January 9 – 12, 2012. (Abstract Submitted)

3. Ruvalcaba, M., Rahman, M., Love, N., and Choudhuri, A., "Analysis of Drag on a non-Spherical Particle," *9th International Energy Conversion Engineering Conference and Exhibit*, AIAA, San Diego, CA, July 31-August 3, 2011(Paper Accepted).

4. Ruvalcaba, M., Love, N., and Choudhuri, A., "Numerical Analysis of Drag on Non-Spherical Particles in Fluidized Beds," *1st Southwest Energy Science and Engineering Symposium*, University of Texas El Paso, El Paso, TX, April 16, 2011.

5. Rahman, M., Love, N., and Choudhuri, A., "Hydrodynamic Analysis of a Fluidized Bed Operating with Spherical and Non-Spherical Particles," *1st Southwest Energy Science and Engineering Symposium*, University of Texas El Paso, El Paso, TX, April 16, 2011.

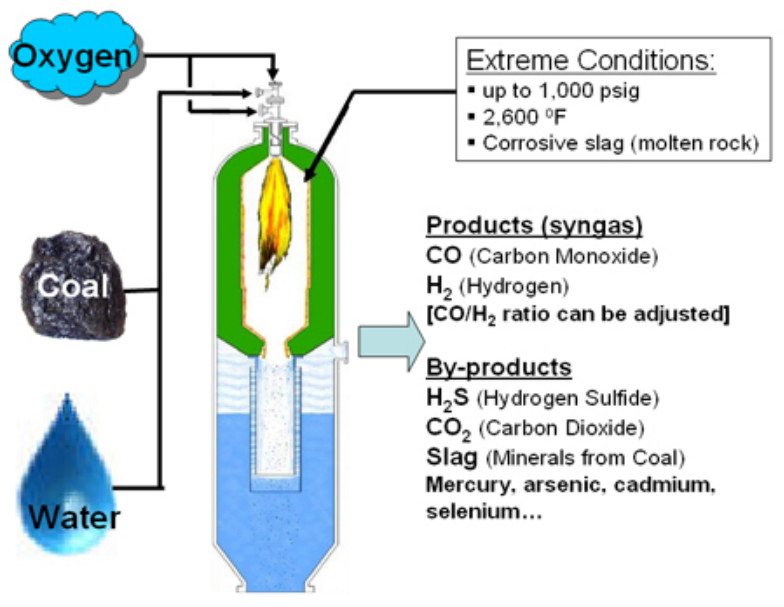
6. Rahman, M., Ruvalcaba, M., Love, N., and Choudhuri, A., "Investigation of Gas-Solid Fluidized Bed Dynamics with Spherical and Non-Spherical Particles," AIAA-2011-0131, *49th Aerospace Sciences Meeting and Exhibit*, AIAA, Orlando, FL, January 4 – 7, 2011.

Introduction

- **Gasifier:**

  Fluidized bed

  - Solid particles become suspended
  - Behave as though they were a fluid
  - Some Applications in Industrial Processes:
    - Catalyst Regeneration
    - Solid-Gas Reactors
    - Combustion of Coal
    - Roasting of Ores
    - Gas Adsorption Operations.



U.S. Department of Energy, Clean Coal & Natural Gas Power Systems,www.fossil.energy.gov/programs /powersystems/gasification/index.html, May 25, 2010

Background

- **2006 Multiphase Workshop-** postulated a set of near-midterm, mid-term, and long-term research needs to attain a significant development in the design, operation, and troubleshooting of multiphase flow devices in fossil fuel processing plants by the year 2015.

- Despite previous efforts on gas-solid flows in a fluidized bed, bed dynamics and particle scale motions are still poorly understood

- A majority of past experimental and computational efforts have been focused on the behavior fluidized bed with spherical particles whereas in most fossil-fuel processes the particles are often non-spherical

Project Objectives

Objective 1: To Obtain Full-Field Visualization of Rotational Motions of Non- Spherical Particles

Objective 2: To Evaluate Drag Force on Non-Spherical Particles

Objective 3: To Incorporate Experimental Data for Non-Spherical Particles in MFIX

Tasks- Overview

Year 1:

- Task 1: Design of the Experimental Setup: Production and Categorization of Non-Spherical Particles
- Task 2: Map fluidization velocities in bed
- Task 3: Terminal Velocity Determination of Free Falling Non-Spherical Particles

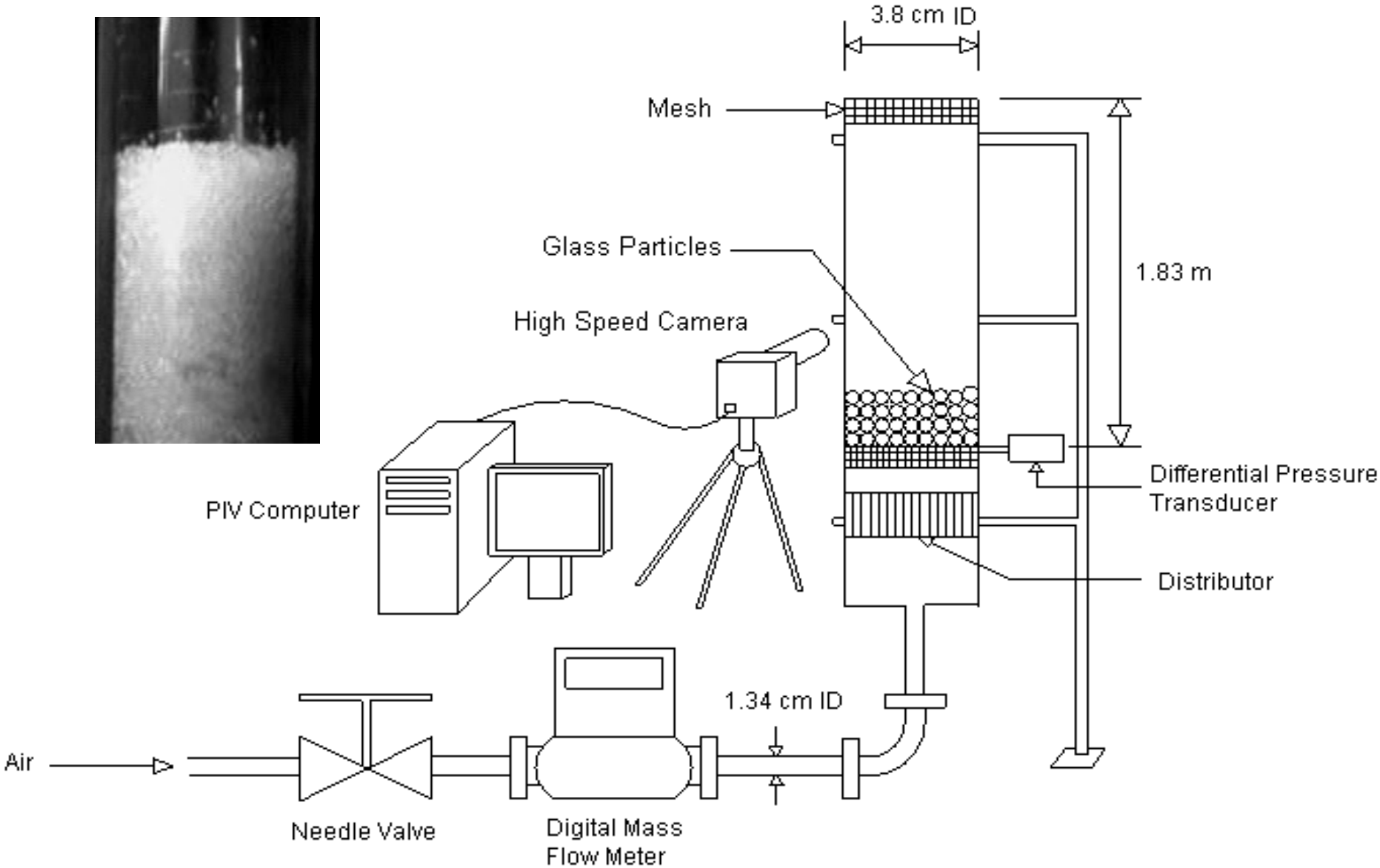
Year 2:

- Task 4: Development of Algorithm for Detection of Non-Spherical Geometries, Particle Pair Identification, Trajectory, and Velocity Components
- Task 5: Integration of the Imaging Instrumentation and Diagnostics with the Experimental Setup
- Task 6: Obtaining Velocity and Drag for Non-Spherical Particles

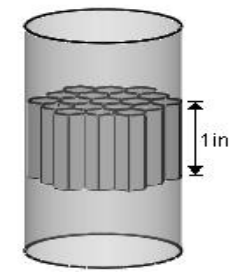
Year 3:

- Task 7: Modeling of Pressure Drop and Terminal Velocities in Fluidized Bed for Non-Spherical Particles
- Task 8: Implement Experimental Drag Relations Using MFIX Numerical Model

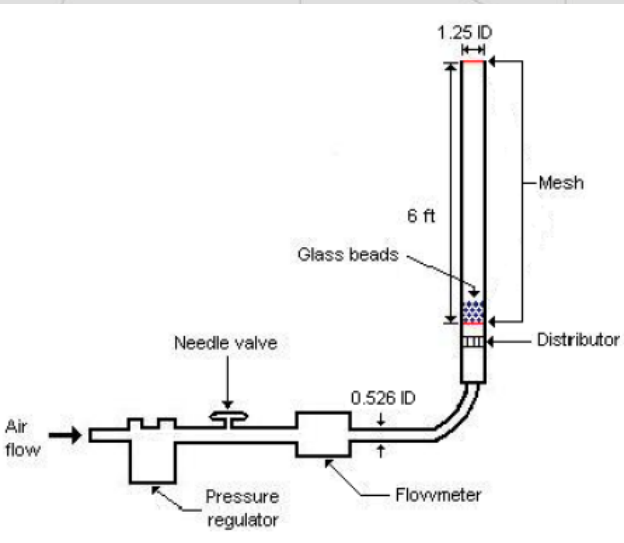
Experimental Setup



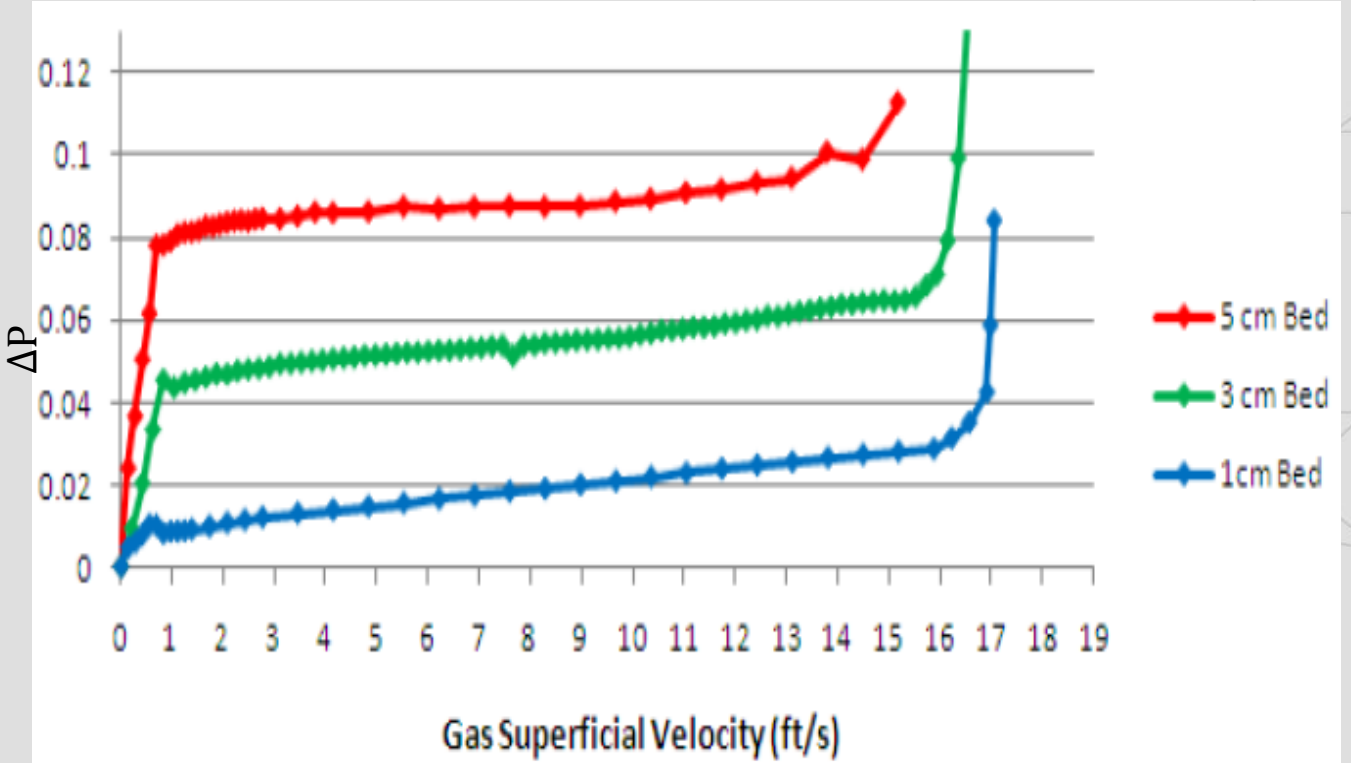
Experimental Setup 1st Gen



1	Pressure Transducer
2	High-Speed Camera
3	LDV

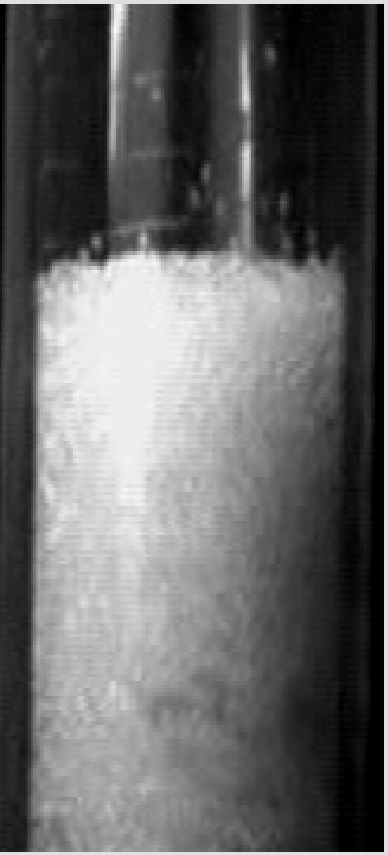


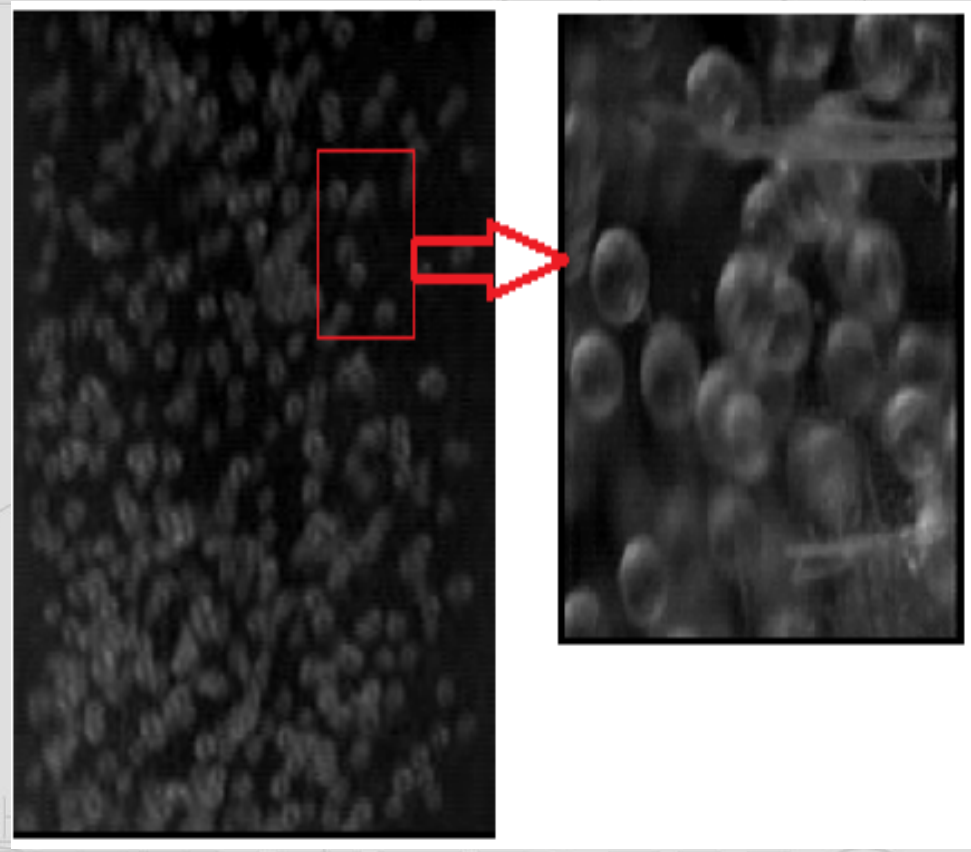
Experimental Setup 2nd Gen



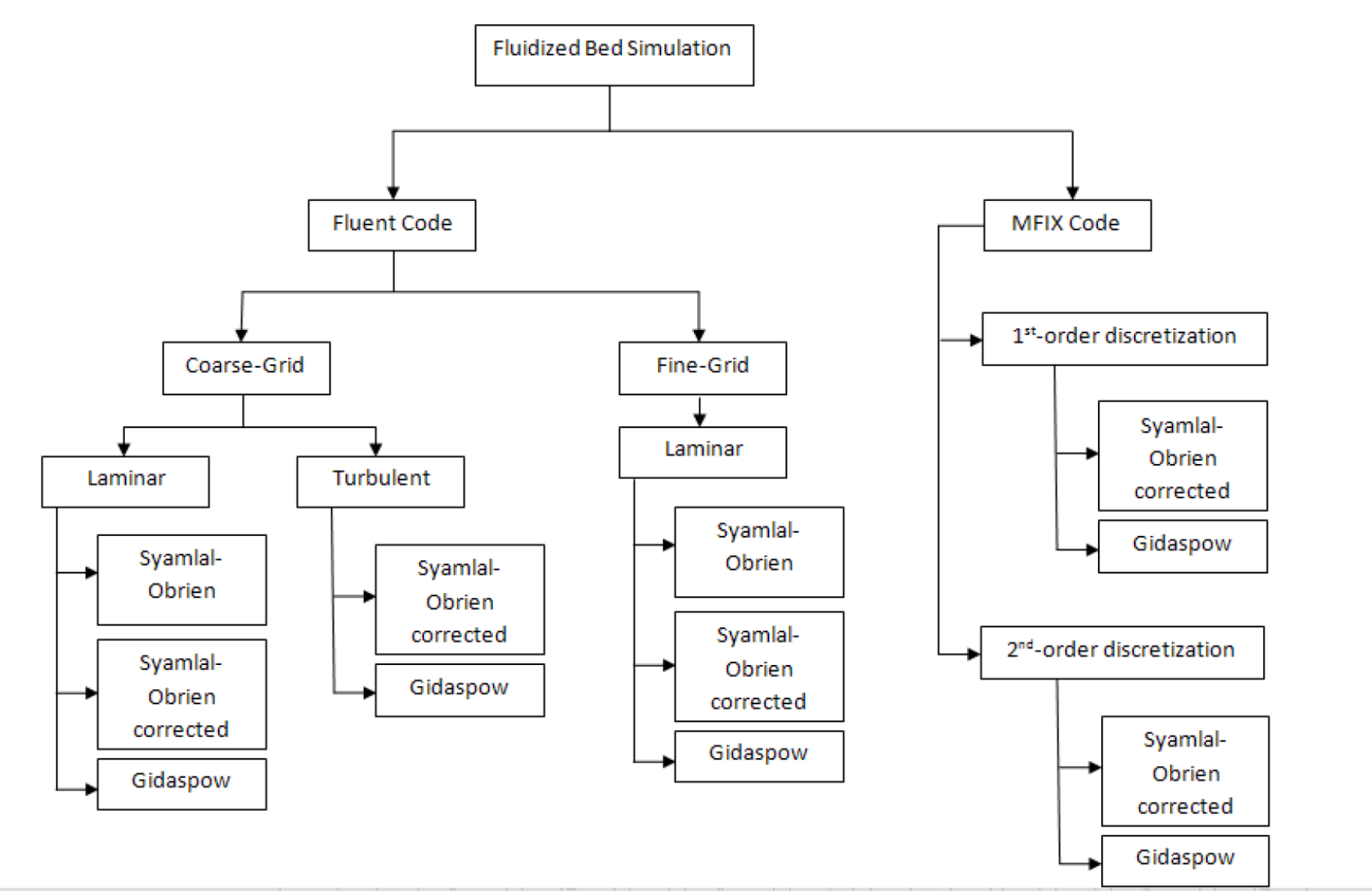
Spherical glass particle
Mean Diameter = 1 mm

Experimental Uncertainty	3.1%





07 03-05-10 STOP 000001
FWD30 0000.0000sec
1/500 START 500FPS


Fluidized Bed Simulation
Fluent Code
MFIX Code
Coarse-Grid
Fine-Grid
Laminar
Turbulent
Laminar
Syamlal-Obrien
Syamlal-Obrien corrected
Gidaspow
Syamlal-Obrien corrected
Gidaspow
Syamlal-Obrien
Syamlal-Obrien corrected
Gidaspow
1st-order discretization
2nd-order discretization
Syamlal-Obrien corrected
Gidaspow
Syamlal-Obrien corrected
Gidaspow

Void Fraction:

$$\varepsilon_g + \varepsilon_s = 1$$

Continuity:

$$\frac{\partial}{\partial t}(\varepsilon_g \rho_g) + \nabla \cdot (\varepsilon_g \rho_g \overrightarrow{v_g}) = 0$$

$$\frac{\partial}{\partial t}(\varepsilon_{sm} \rho_{sm}) + \nabla \cdot (\varepsilon_{sm} \rho_{sm} \overrightarrow{v_{sm}}) = 0$$

Momentum:

$$\frac{\partial}{\partial t}(\varepsilon_g \rho_g \overrightarrow{v_g}) + \nabla \cdot (\varepsilon_g \rho_g \overrightarrow{v_g}\,\overrightarrow{v_g}) = \nabla \cdot \overline{\overline{S_g}} + \varepsilon_g \rho_g \vec{g} - \overrightarrow{I_{gs}}$$

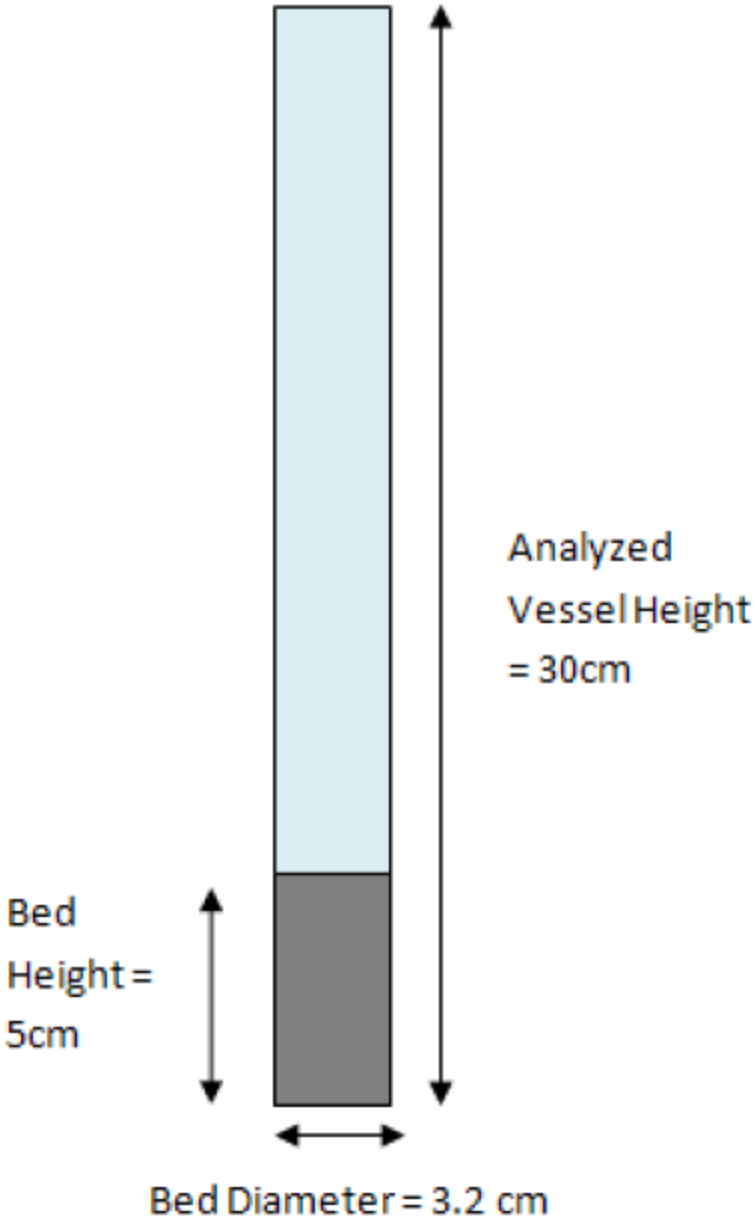
$$\overrightarrow{I_{gs}} = -\varepsilon_s \nabla P_g - F_{gs}(\overrightarrow{v_s} - \overrightarrow{v_g})$$

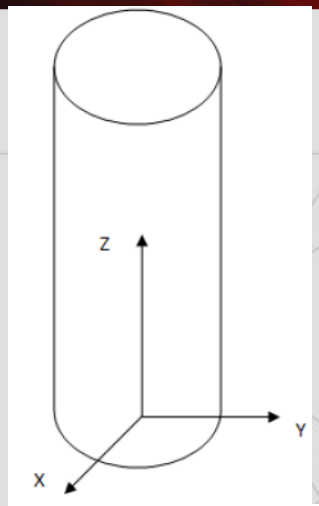
$$\frac{\partial}{\partial t}(\varepsilon_{sm} \rho_{sm} \overrightarrow{v_{sm}}) + \nabla \cdot (\varepsilon_{sm} \rho_{sm} \overrightarrow{v_{sm}}\,\overrightarrow{v_{sm}}) = \nabla \cdot \overline{\overline{S_{sm}}} + \varepsilon_{sm} \rho_{sm} \vec{g} + \overrightarrow{I_{gs}} - \overrightarrow{I_{ml}}$$

$$\overrightarrow{I_{ml}} = F_{ml}(\overrightarrow{v_{sl}} - \overrightarrow{v_{sm}})$$

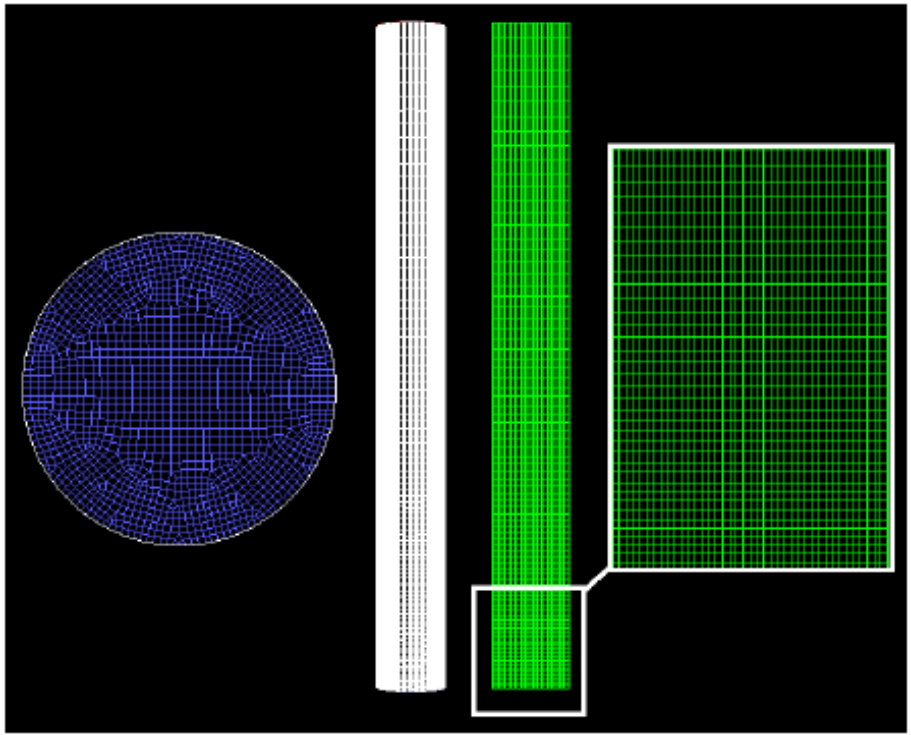
Drag Force F_{ml}, F_{gs}: **Syamlal-Obrien Correlation**

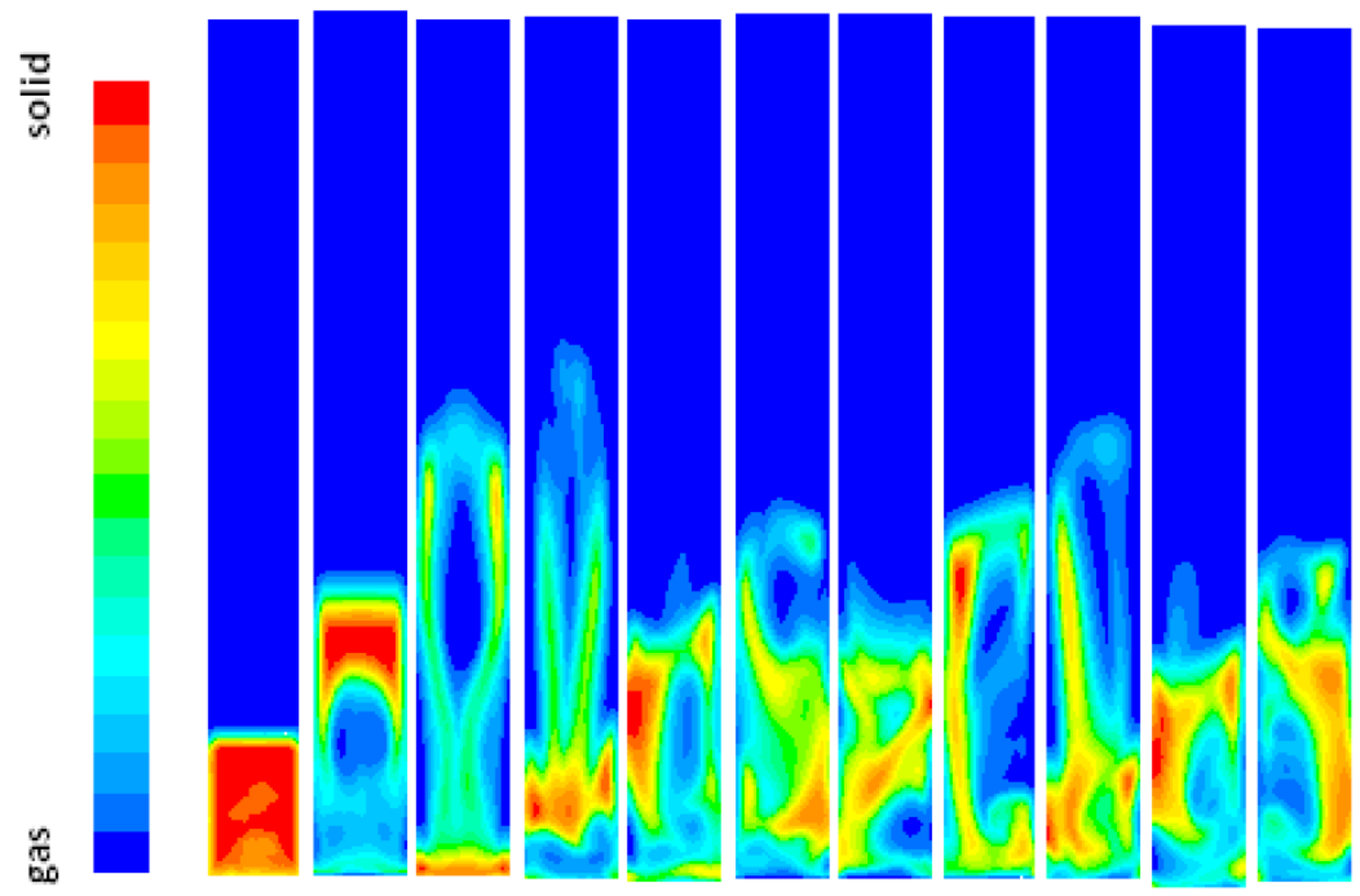
Gidaspow Correlation





$\varepsilon_g = 0.45$
Velocity Inlet
Pressure Outlet
No-Slip Walls

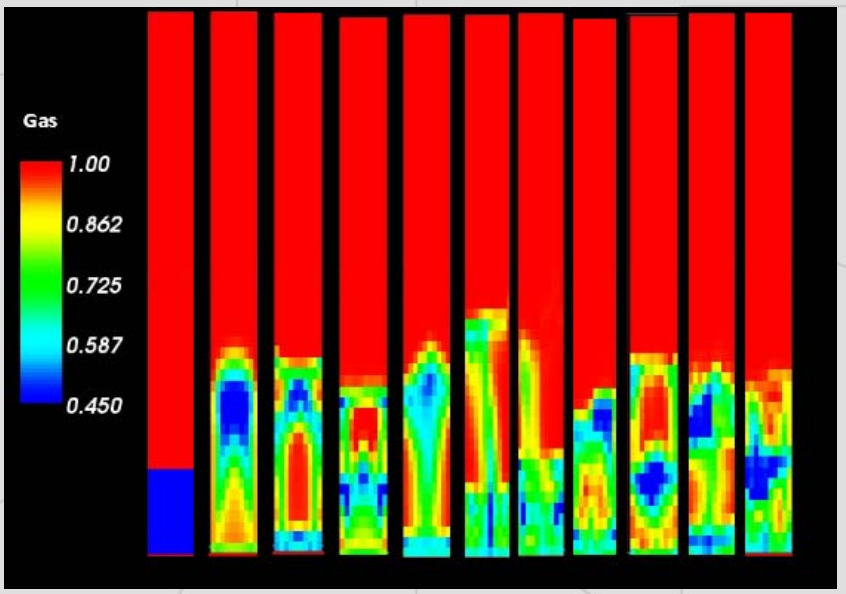


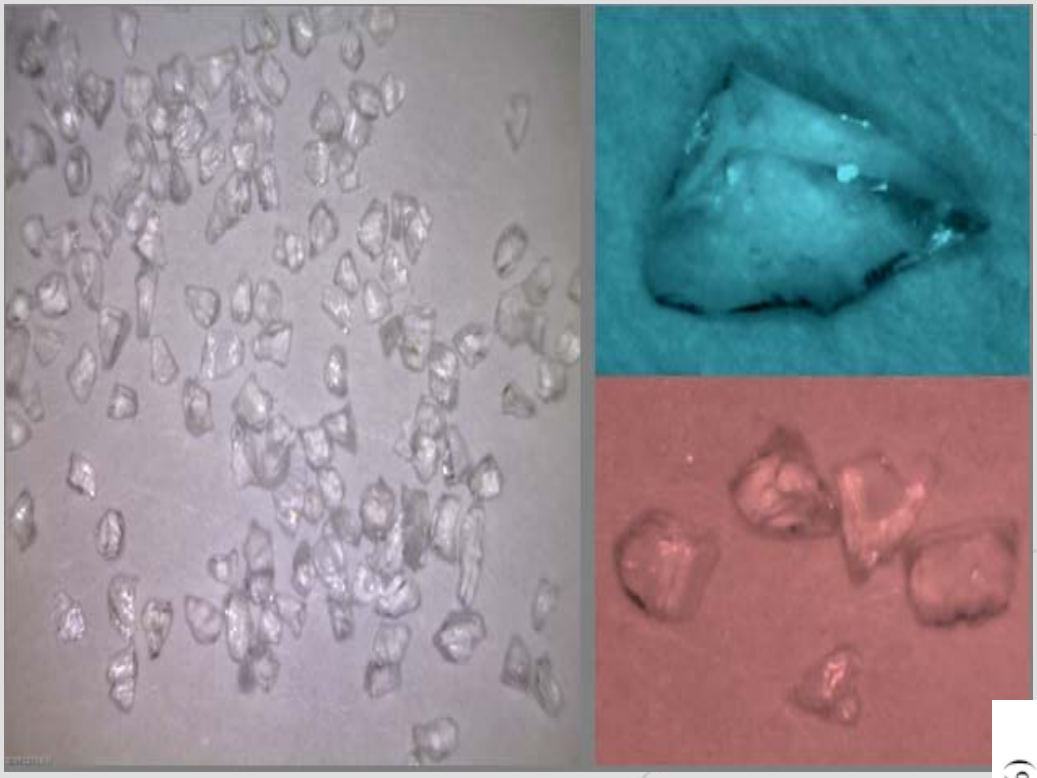


Correlation	Minimum Fluidization Velocity (cm/s)	Flow Rate (Lpm)
Experimental	21.00	10.00
Fluent	51.81	25.00

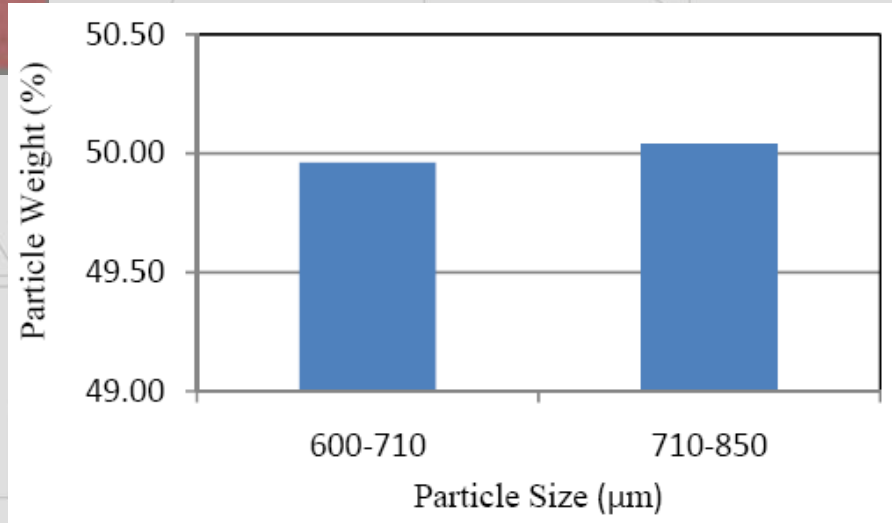
MFIX (Multiphase Flow with Interphase eXchanges)

- NETL
- Hydrodynamics, heat transfer and chemical reactions in fluid-solids systems





Non-spherical glass particle
Mean Diameter = 0.7 mm



- **Sphericity:**

➢ Method to measure the sphercity of a particle[3]:

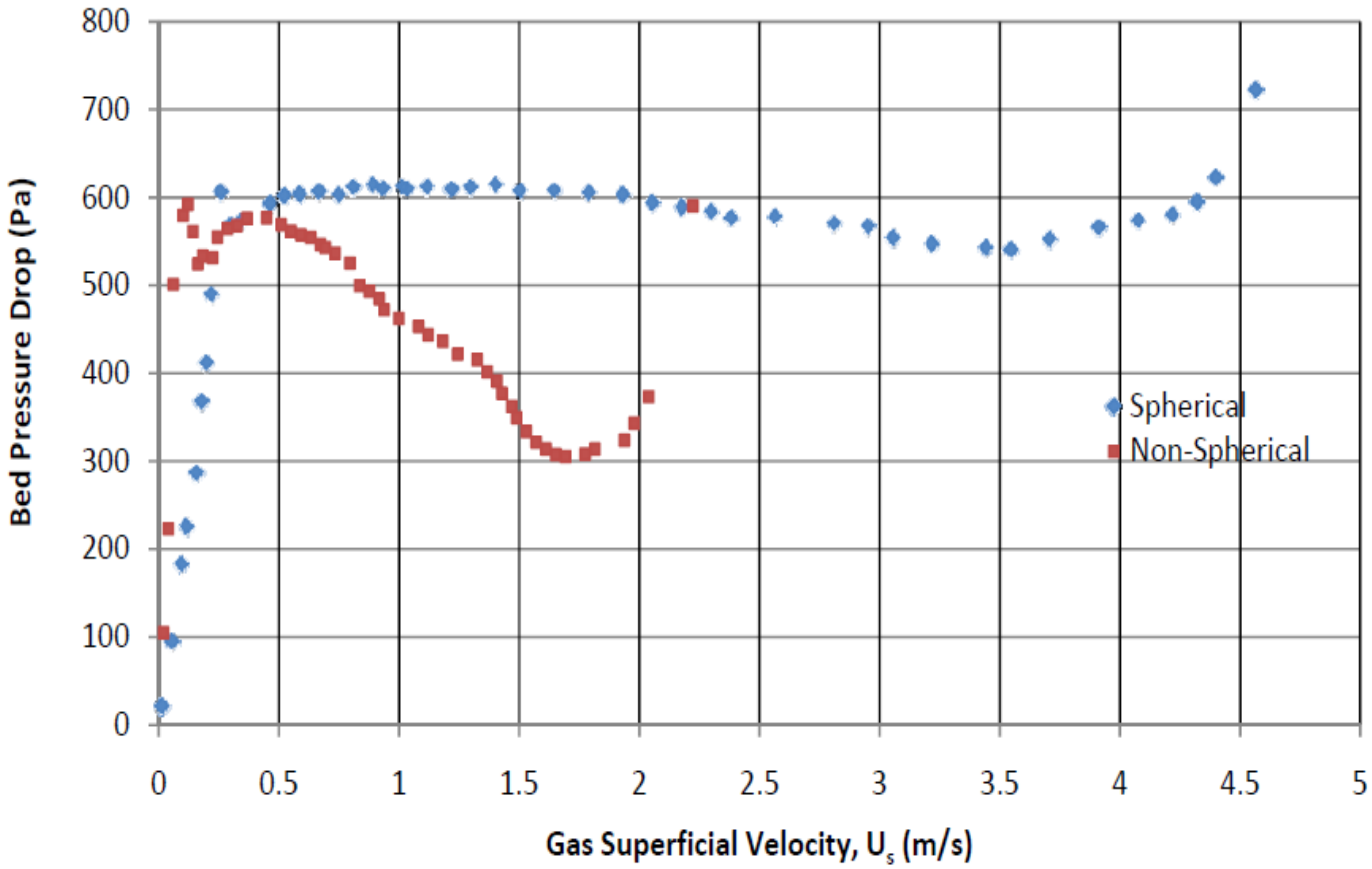
$$\varphi = \sqrt[3]{\frac{b\,c}{a^2}}$$

a, b, c are the diameters of a tri-axial ellipsoid, and a>b>c

➢ Spherical particle sphericity variation ± 10 %

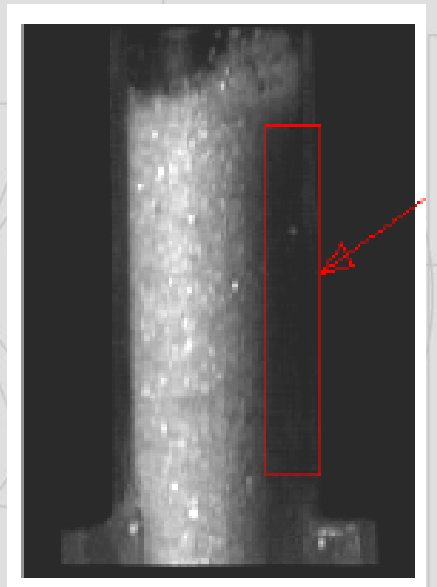
➢ Non-spherical glass particle average sphericity was found to be 0.7

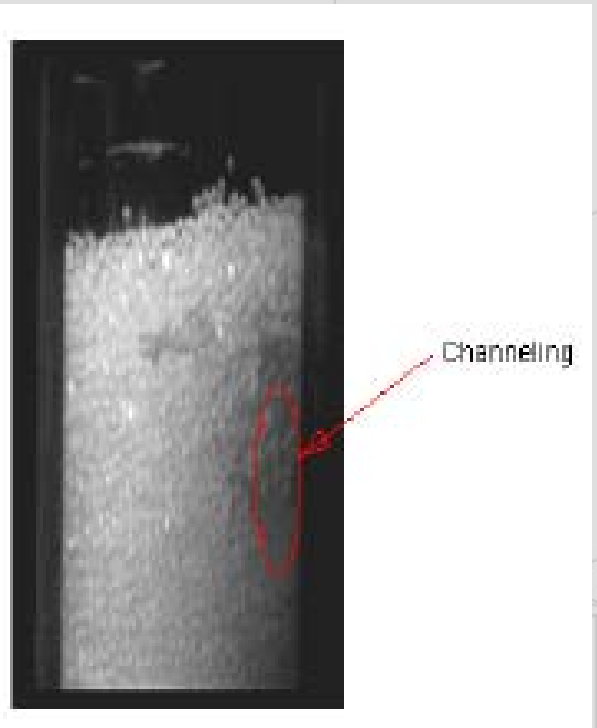
[3]SAM BOGGS, JR., "MEASUREMENT OF ROUNDNESS AND SPHERICITY PARAMETERS USING AN ELECTRONIC PARTICLE SIZE ANALYZER," *Journal of Sedimentary Petrology*, Vol. 37, No. 3, 1967, pp. 907-913.



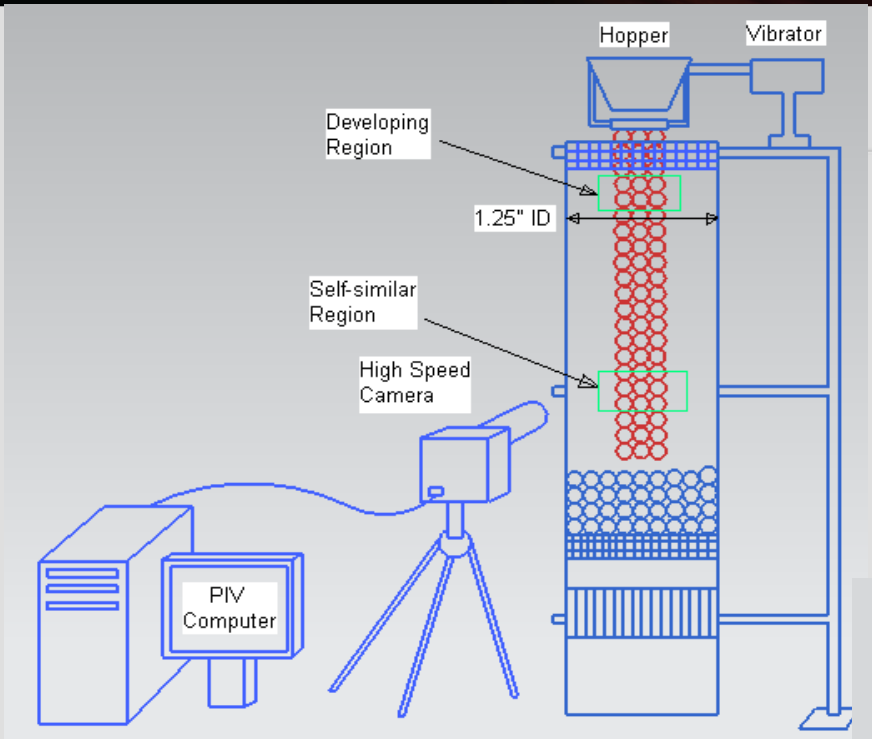
Experimental Uncertainty	4.1%

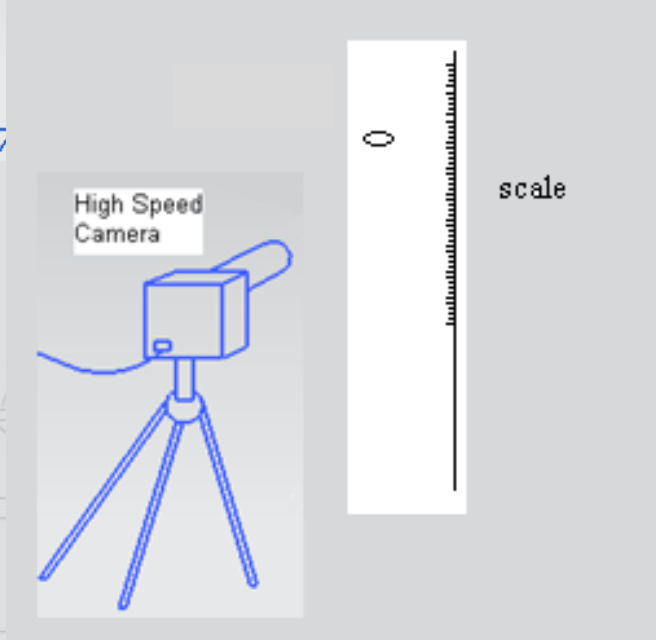
- Higher channeling for non-spherical particles
- Pressure drop due to high velocities





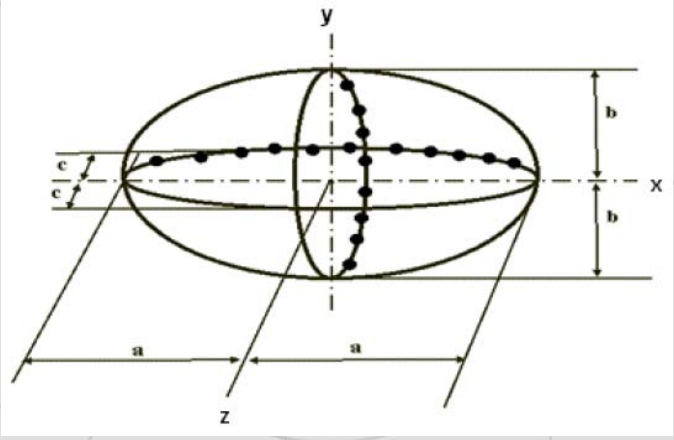
- Channeling caused non-uniform distribution of fluid and solid inside of bed


Hopper
Vibrator
Developing Region
1.25" ID
Self-similar Region
High Speed Camera
PIV Computer


High Speed Camera
0
scale

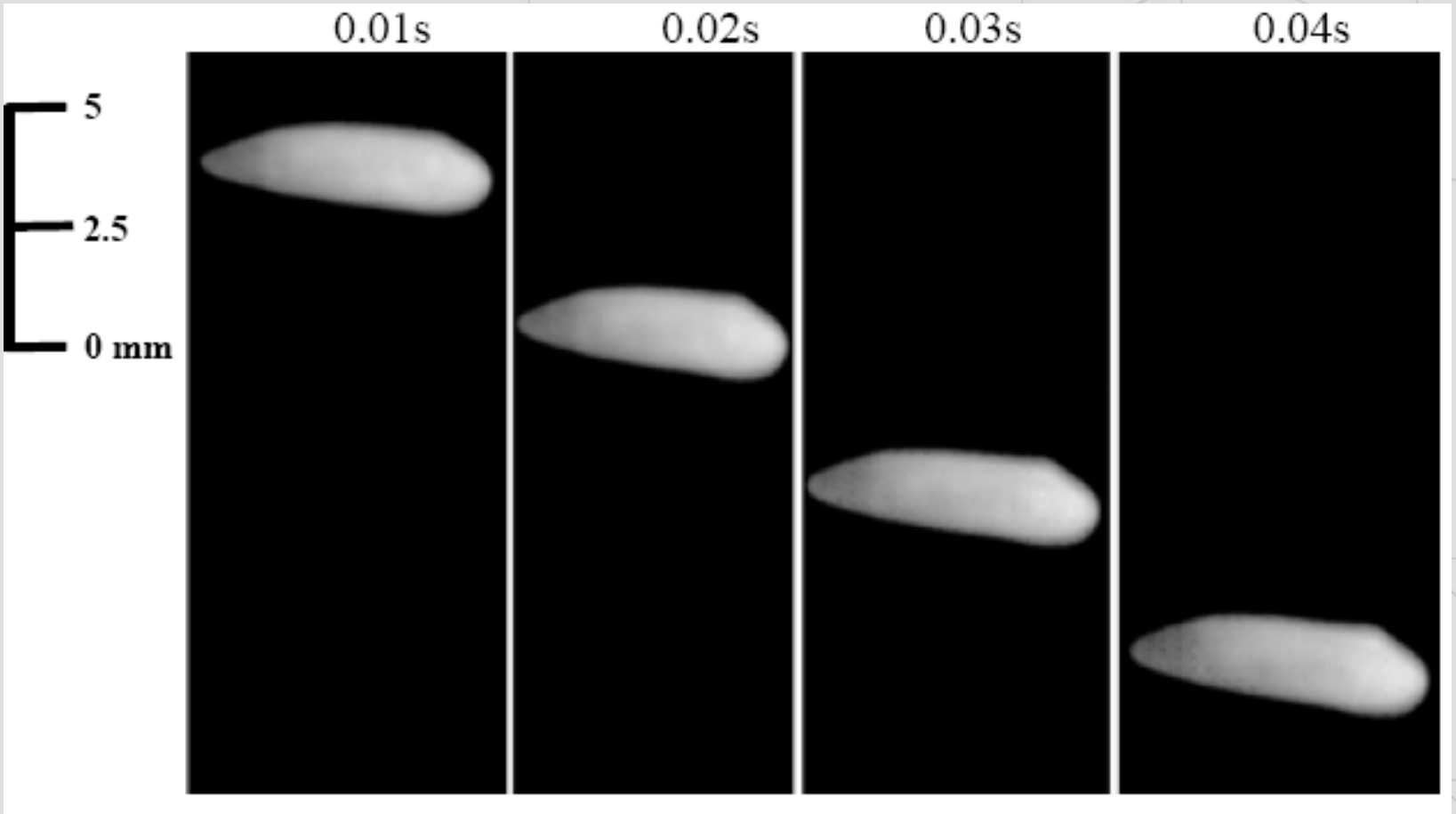
- The rice grains were assumed to ellipsoid in shape
- The Eqn. used to determine the initial terminal velocity :

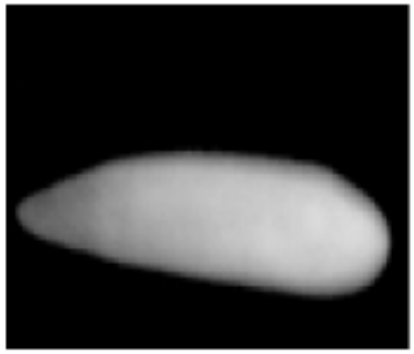
$$v_t = \sqrt{\frac{8\,bg}{3\,C_D}\frac{(\rho_s - \rho_f)}{\rho_f}}$$



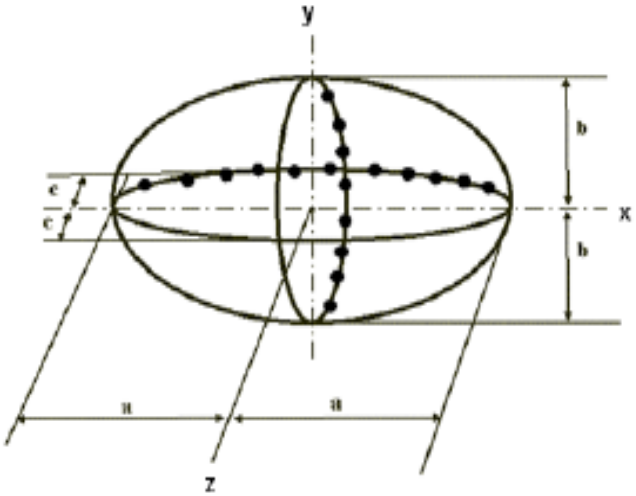
where V_t is the terminal velocity, b is the mean polar diameter along the y-axis, ρ_s is the density of rice grain, ρ_f is the density of air, and C_D is the drag coefficient initially assumed to be 0.6.

- Rice density 577 kg/m^3
- Air density as 1.2 kg/m^3
- 3100 frames per second

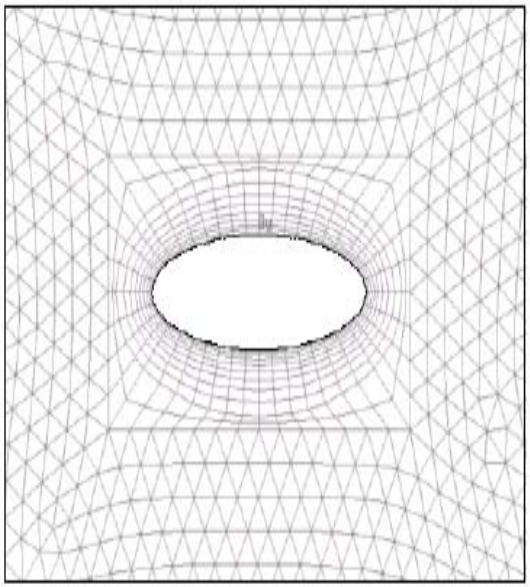

0.01s
0.02s
0.03s
0.04s
5
2.5
0 mm

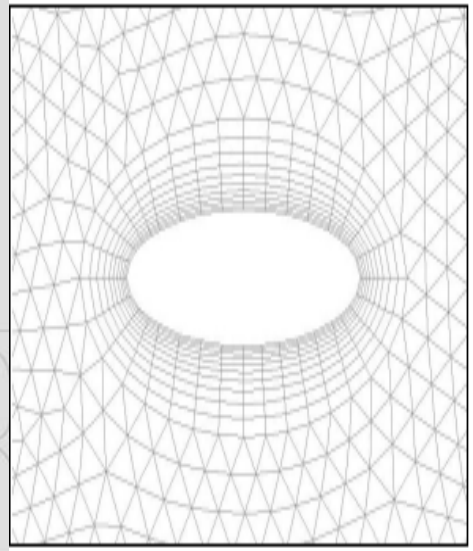


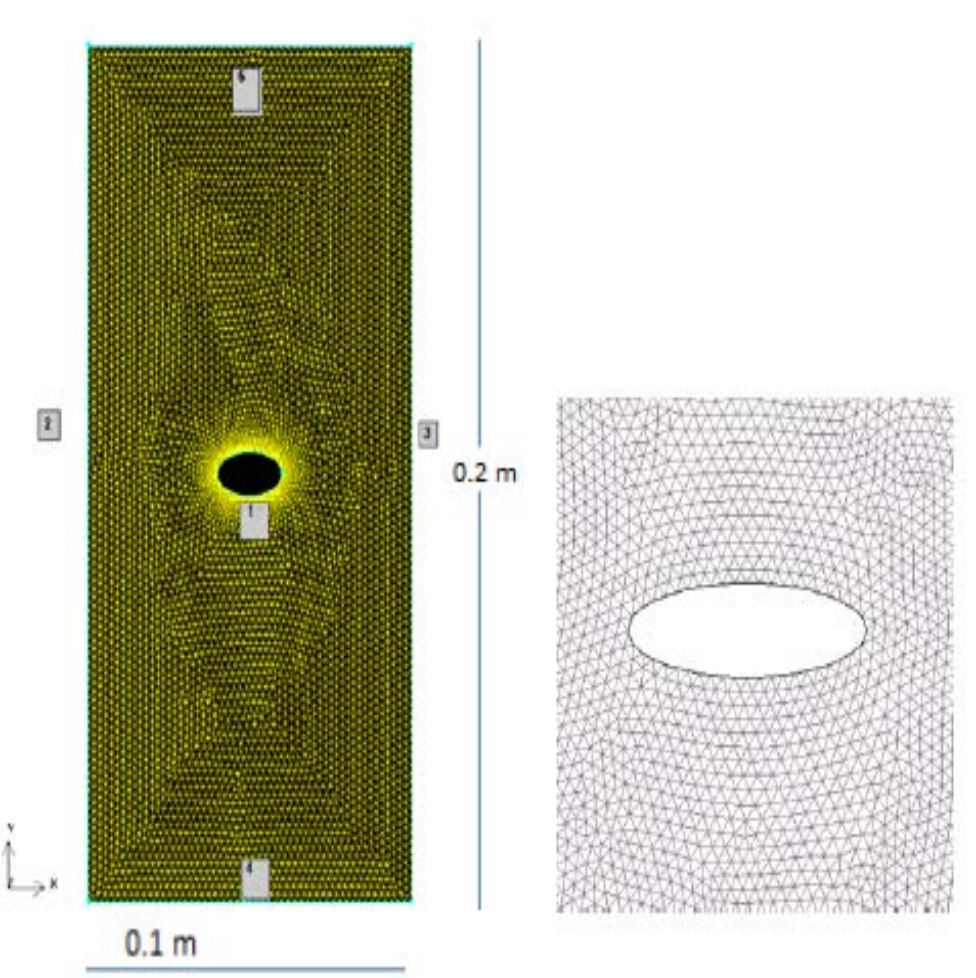
a)



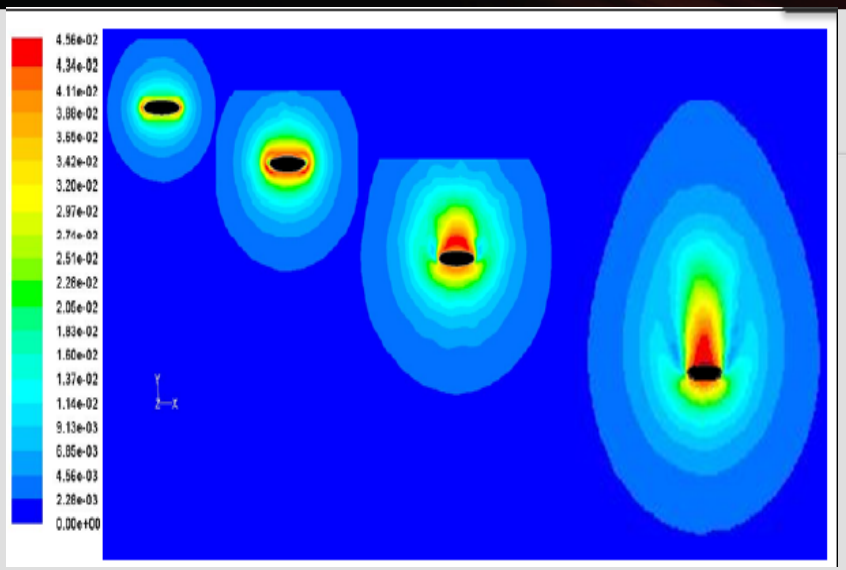
b)

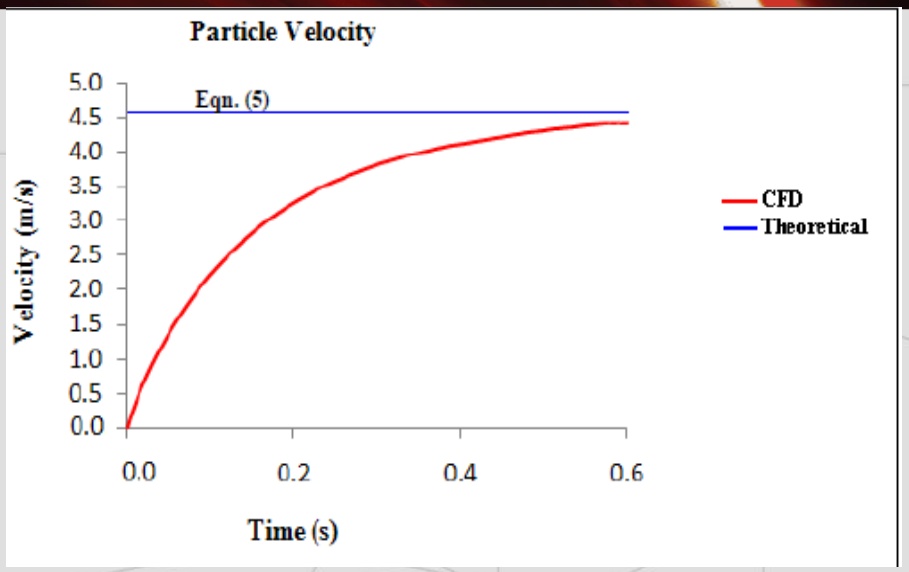




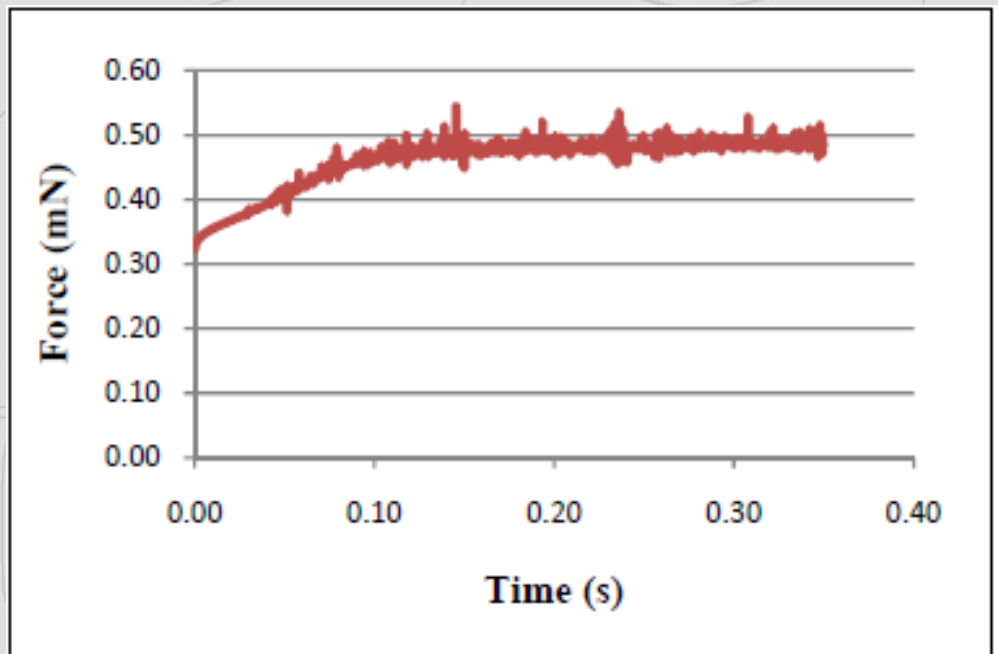


Boundary No.	Boundary Condition
1	Moving Wall
2	Pressure Outlet
3	Pressure Outlet
4	No-Slip Wall





Results	Numerical	Experimental
Re	1058	1081
C_D	0.5	0.58



Summary and Highlights to Date

- Fluidized bed design & experimental setup
- Implementation of high-speed imaging
- Non-spherical particle
  - Production
  - Pressure drop
  - Categorization
- Drag Analysis

THE CHANGING FACE OF ENGINEERING

Anticipated Efforts for the Upcoming Year

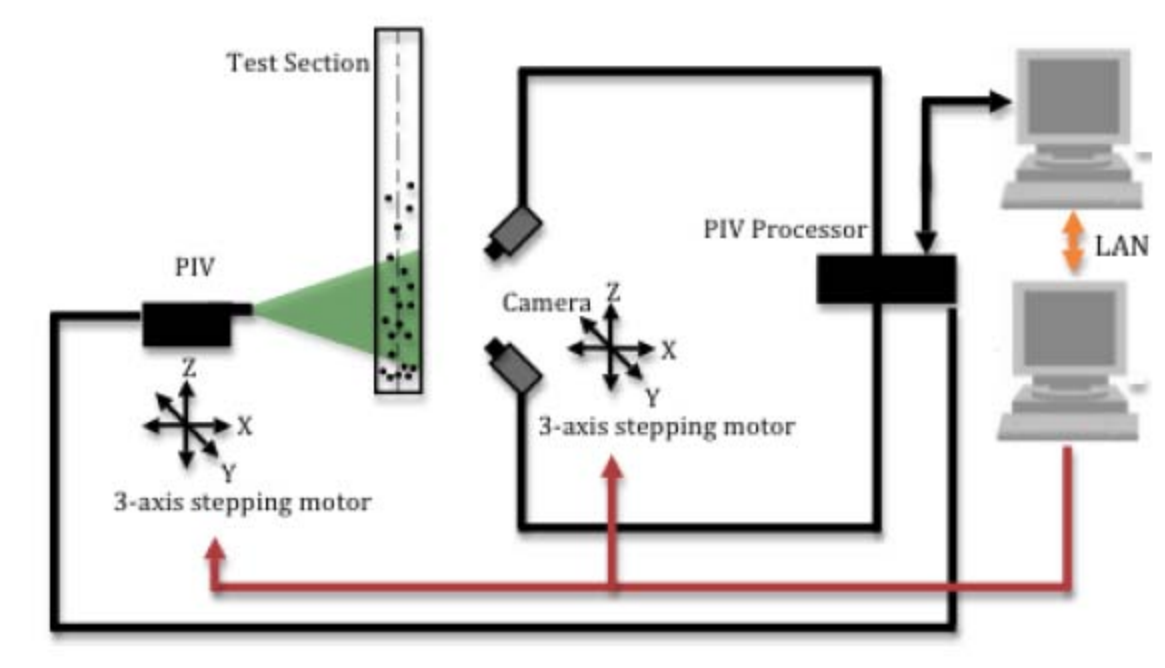
- Detection of Non-Spherical Geometries, Particle Pair Identification, Trajectory, and Velocity Components

- Obtaining Velocity and Drag for Non-Spherical Particles
  - C_D vs. Re
  - Various geometry particles

THE CHANGING FACE OF ENGINEERING

Anticipated Efforts for the Upcoming Year

- Integration of the Imaging Instrumentation and Diagnostics with the Experimental Setup
  - High-speed stereo PIV
  - MatPIV



Contact Information

If you have any questions or would be interested in collaboration please contact

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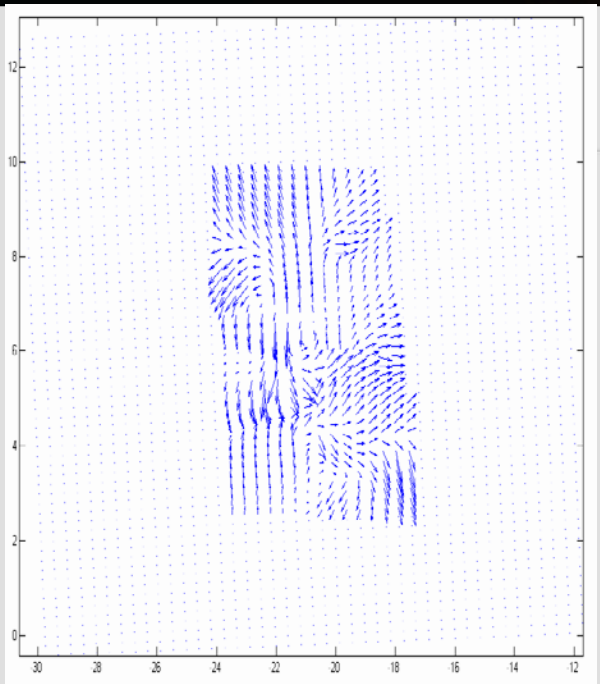
ADDITIONAL SLIDES

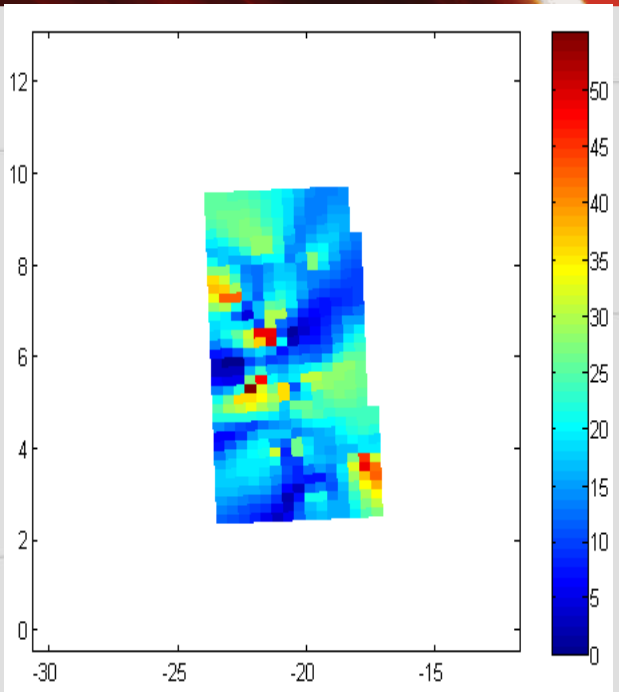
MatPIV

- A toolbox similar to Particle Image Velocimetry (PIV) ran with MATLAB
- Uses pattern matching techniques found in PIV fundamentals
- RGB to Intensified Image.

Spherical

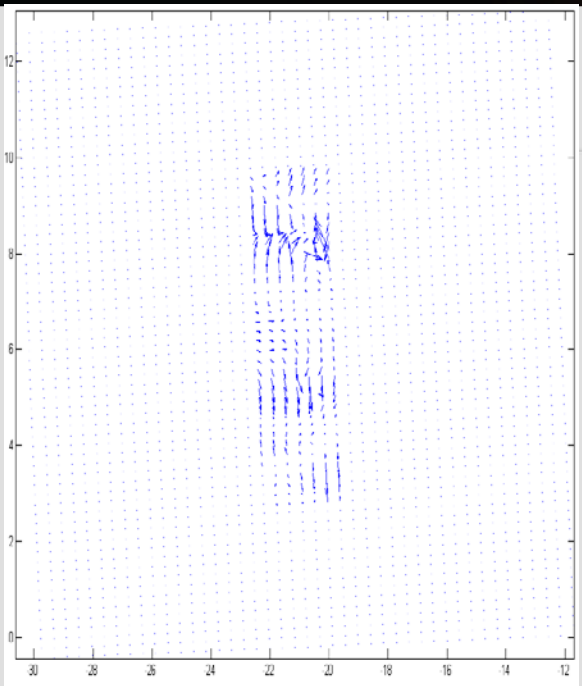


Velocity Vector

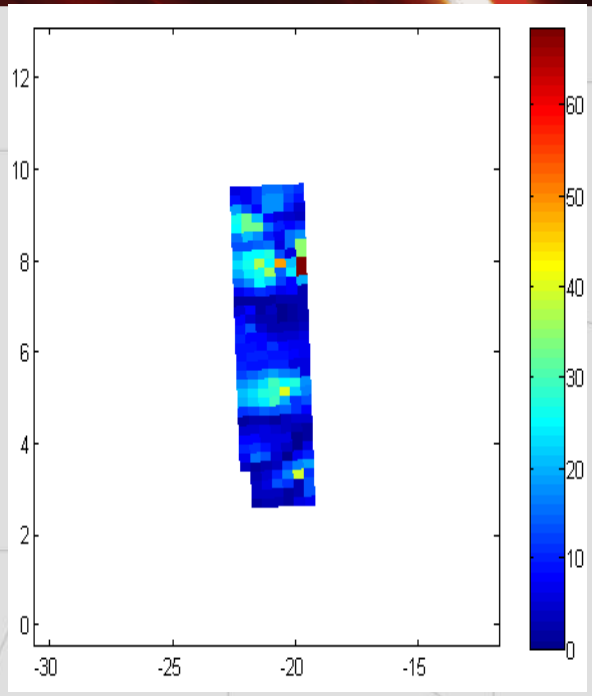


Velocity Magnitude

Non Spherical



Velocity Vector



Velocity Magnitude