Application of the Particle In Cell Approach for the Simulation of Bubbling Fluidized Beds of Geldart A Particles

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Outline

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- Model development
  - Model set up and parameters
  - Drag models
- Results
  - Bed expansion
  - Bubble size and velocity
  - Bubble solid fraction
- Conclusion

CFD simulation of a bubbling fluidized bed of Geldart A particles

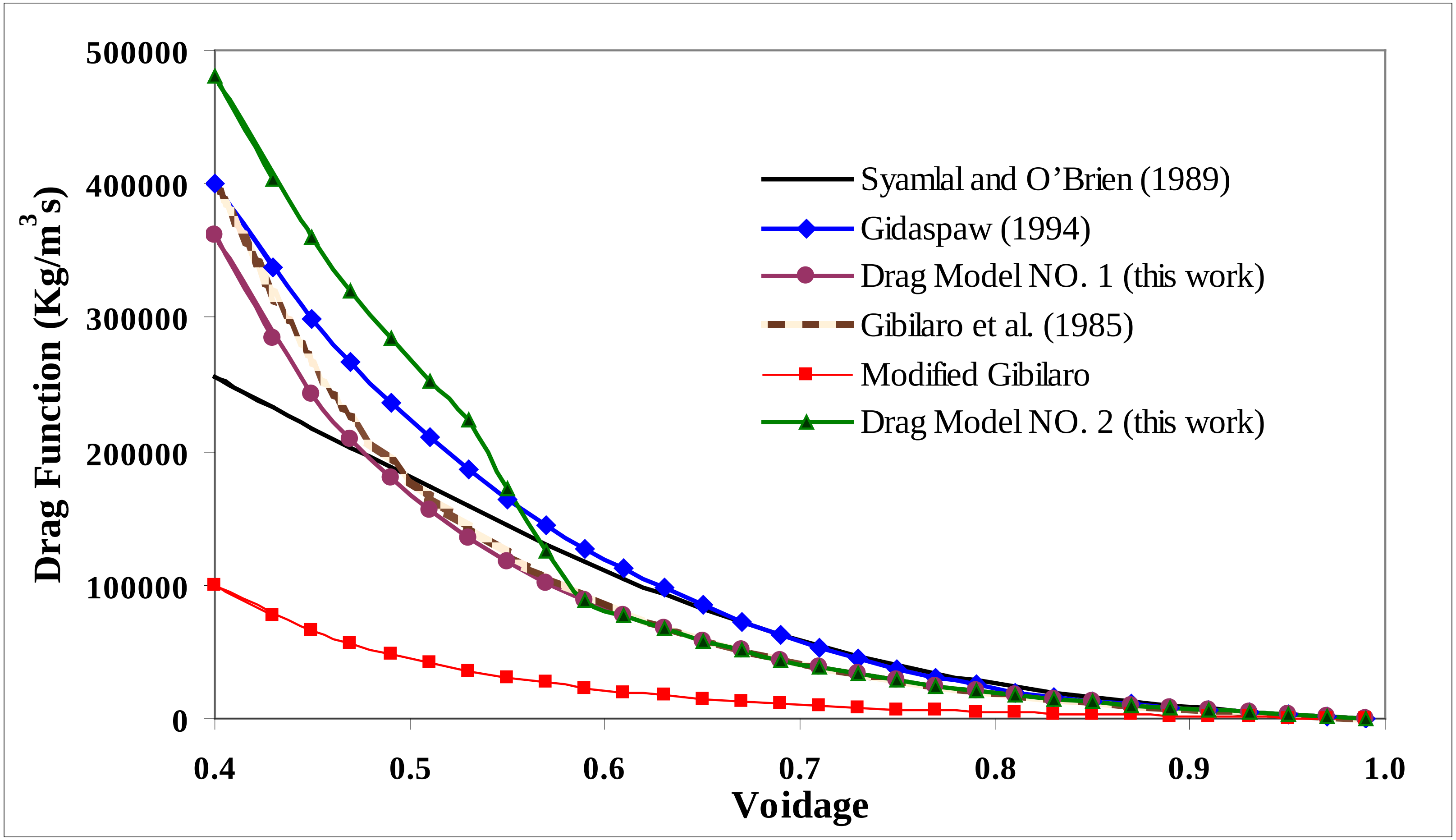
- Background
  - McKeen and Pugsley [Powder Technol. 129(1-3), 139-152, 2003] used MFIX to model a bubbling bed of *Geldart A* powder – Eulerian approach
  - 2-D model, mean particle diameter (no size distribution)
  - Model severely overestimated bed expansion and did not predict the formation of bubbles
  - Sensitivity analysis led us to focus on the gas-solid drag
  - Drag model of Gibilaro et al. reduced by a fractional constant, C
  - Model predictions of bed expansion and bubble properties agreed much better with literature data and data from our own lab

$$\boldsymbol{F}_{gs} = \boldsymbol{C}\left(\frac{17.3}{\mathrm{Re}_{p}} + 0.336\right)\frac{\rho_g \left|\vec{\boldsymbol{v}}_s - \vec{\boldsymbol{v}}_g\right|}{\boldsymbol{d}_p}\boldsymbol{\varepsilon}_s \boldsymbol{\varepsilon}_g^{-1.8}$$

  - Also modeled deaeration test of FCC catalyst with MFIX and modified drag
  - Excellent agreement with data for the deaeration portion of the curve

CFD simulation of a bubbling fluidized bed of Geldart A particles

- Drag models



Bubbling Bed Validation Study

2D Cartesian Coordinates

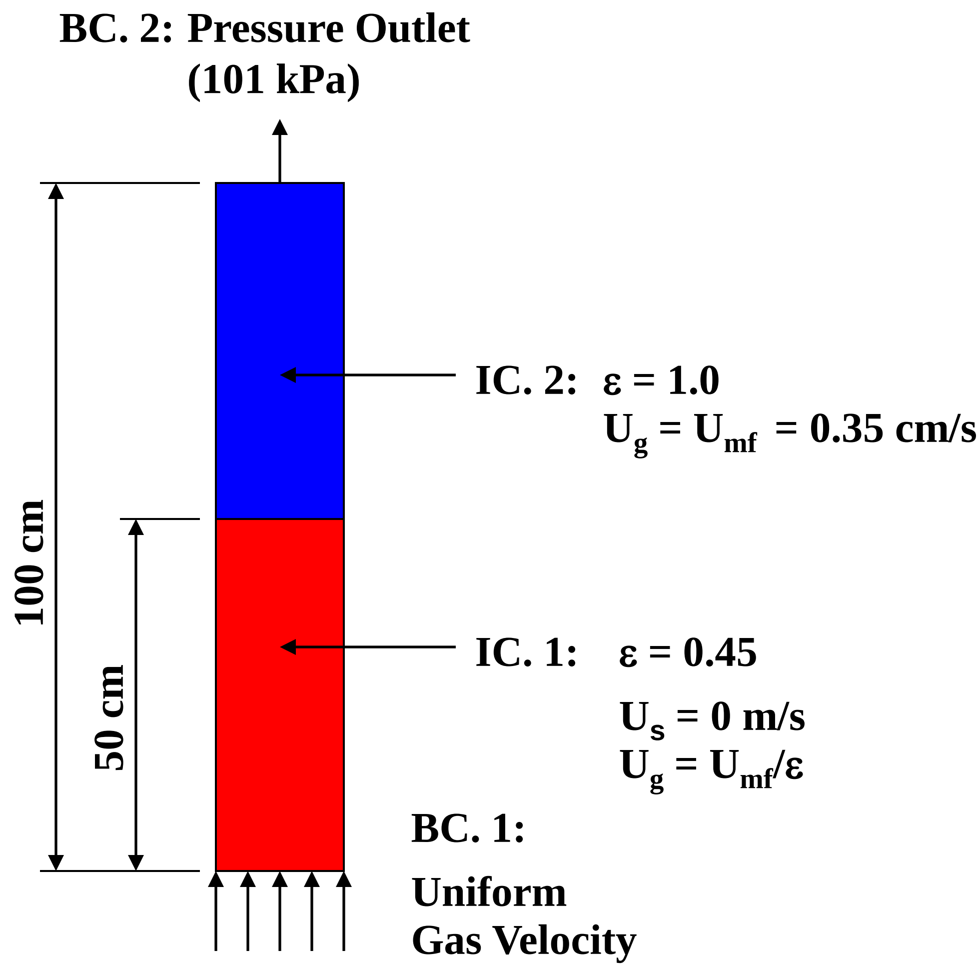
Uniform 0.5 cm Grid

Solids:

d_p = 75 μm

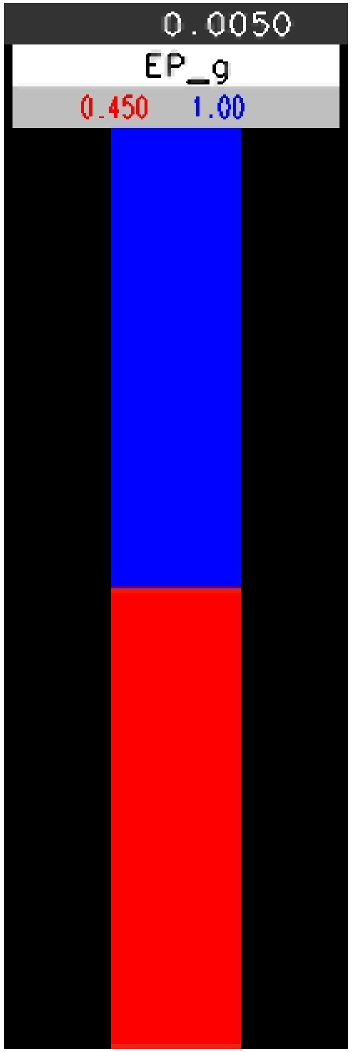
ρ_p = 1500 kg/m³

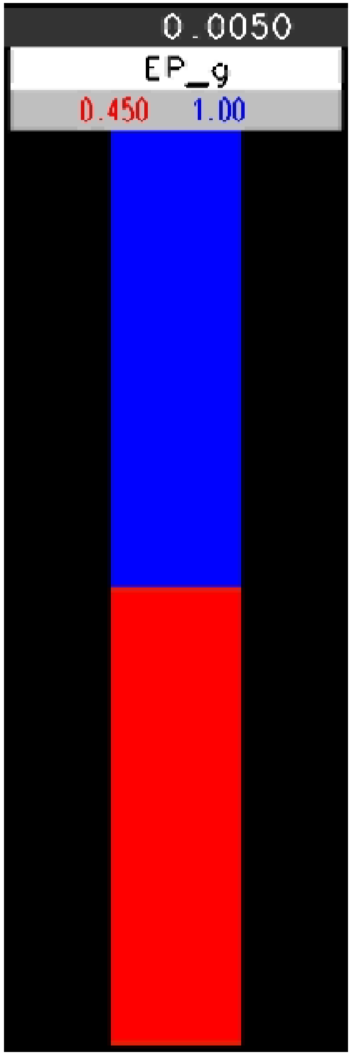
Gas:
Air at 24 C



CFD simulation of a bubbling fluidized bed of Geldart A particles

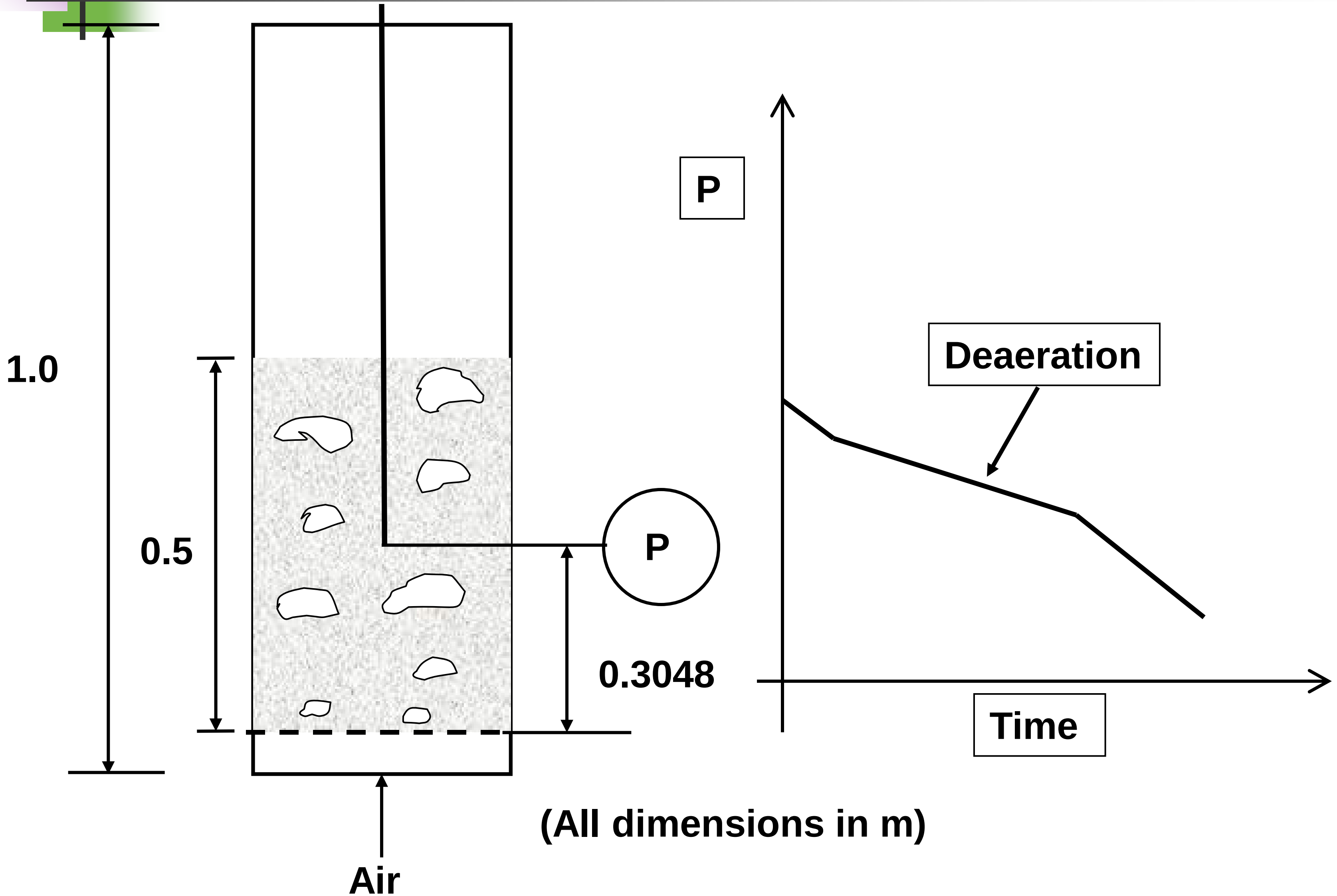
C = 1.0





C = 0.15

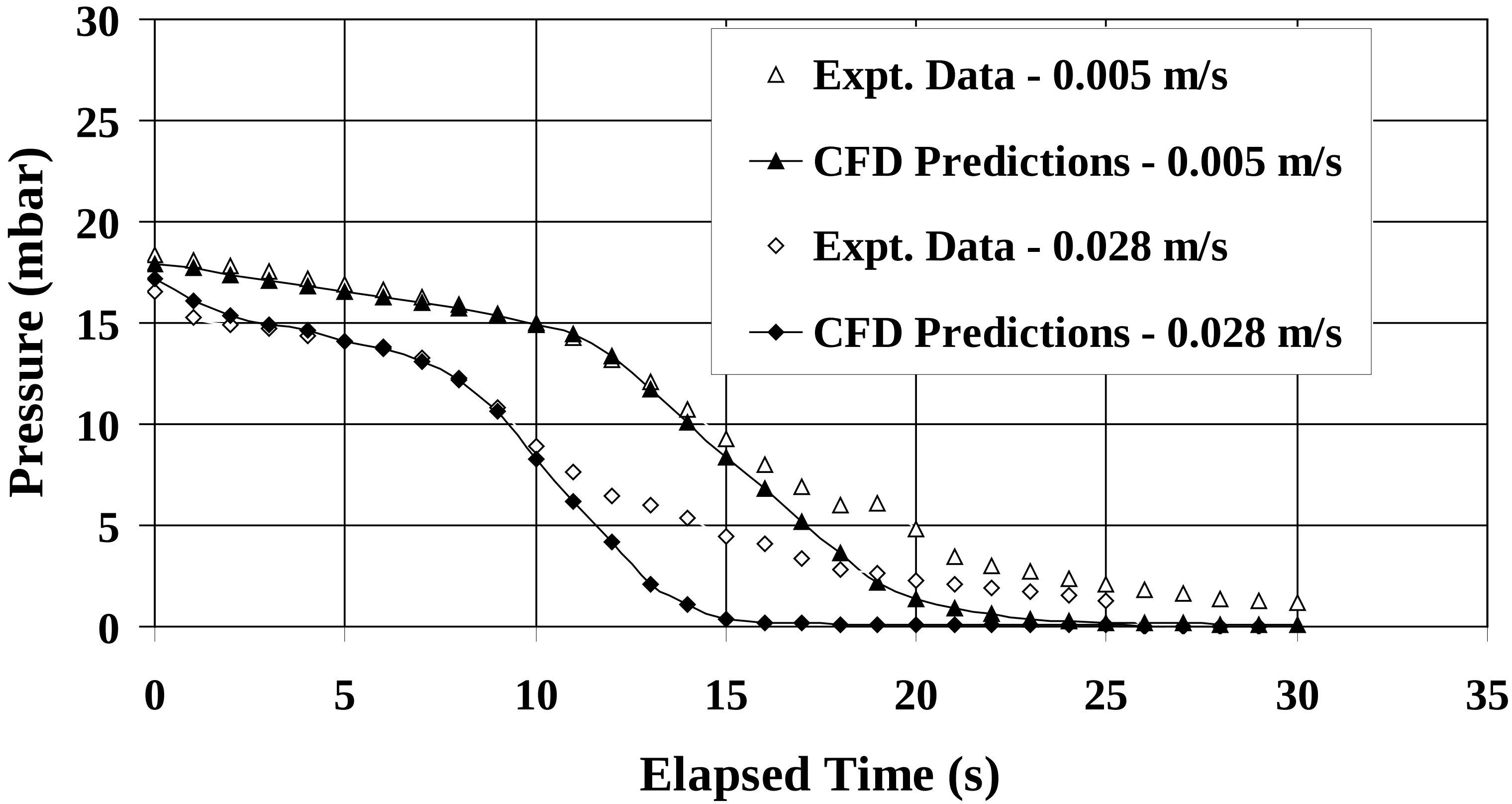
Deaeration Test Model



(All dimensions in m)

Deaeration Test Model

Comparison with pressure vs time data



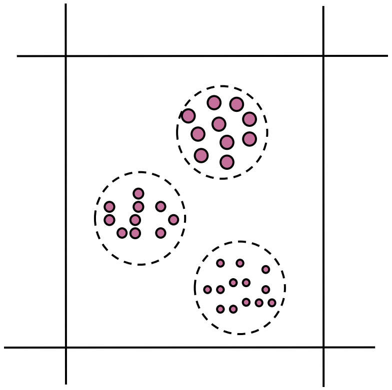
CFD simulation of a bubbling fluidized bed of Geldart A particles

- Motivation for current work
  - Rudimentary treatment of the drag force
  - No particle size distribution incorporated into model
  - Long computation times for 3D models
  - Interested in extending modeling work to capture gas streaming in bubbling beds

- Objective of the present study
  - To assess the particle-in-cell (PIC) approach as a means of predicting Geldart A fluidized bed behavior
  - PIC approach implemented using the Barracuda code from CPFD Software (Albuquerque, NM)
  - Validate results by comparison with experimental data

CFD simulation of a bubbling fluidized bed of Geldart A particles

- Introduction
  - PIC as an Eulerian-Lagrangian approach
    - Parcels have same number of particles with similar:
      - Size
      - Density
      - Velocity
      - Position



Eulerian Part (Fluid phase)

$$\frac{\partial(\varepsilon\rho_g)}{\partial \boldsymbol{t}} + \nabla_x(\varepsilon\rho_g \boldsymbol{u}_g) = 0$$

$$\frac{\partial(\varepsilon\rho_g \boldsymbol{u}_g)}{\partial t} + \nabla_x(\varepsilon\rho_g \boldsymbol{u}_g \boldsymbol{u}_g) = -\nabla_x p + \varepsilon\mu_g \nabla^2 \boldsymbol{u}_g - \boldsymbol{F} + \varepsilon\rho_g g$$

Lagrangian Part (Particle phase)

$$\frac{\partial f}{\partial t} + \nabla_x(f\boldsymbol{u}_p) + \nabla_{\boldsymbol{u}_p}(fA) = 0$$

$$A = \frac{1}{\rho_p} D(\boldsymbol{u}_g - \boldsymbol{u}_p) - \frac{1}{\rho_p}\nabla_x p + g - \frac{1}{\theta\rho_p}\nabla_x \tau$$

$$\boldsymbol{F} = \iiint f V_p \rho_p \left[D(\boldsymbol{u}_g - \boldsymbol{u}_p) - \frac{1}{\rho_p}\nabla p \right] dV_p\, d\rho\, d\boldsymbol{u}_p$$

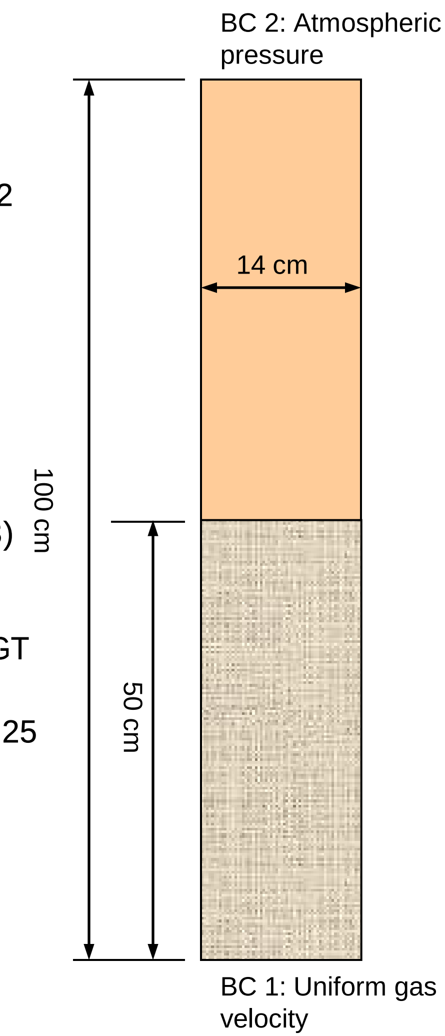
CFD simulation of a bubbling fluidized bed of Geldart A particles

Model set up and parameters

Geometry	Three-dimensional, Cartesian
Vessel dimension	0.14 m diameter and 1 m height
Grid	0.5*0.5*0.5, 1*1*1, 2*2*2 cm
Total number of particles	1.31472e+10
Total number of clouds	3.8944e+6
Granular viscosity model	Lun et al. (1984)
Drag models	NO. 1: Wen and Yu (1966) NO. 2: Modified Gidaspow (1994)
Flow type	Compressible with no gas-phase turbulence
Simulation time	25 seconds
Time step	0.0001 seconds
Pressure-Velocity coupling	SIMPLE
Solid fraction at maximum packing	0.55
Initial condition	Bed at minimum fluidization
Minimum fluidization velocity	0.004 m/s
Minimum fluidization voidage	0.45
Boundary conditions	Uniform flow from bottom Atmospheric pressure at the top
Gas superficial velocity	0.1 m/s
Bed depth	0.5 m
Restitution coefficient	0.4 (Default)

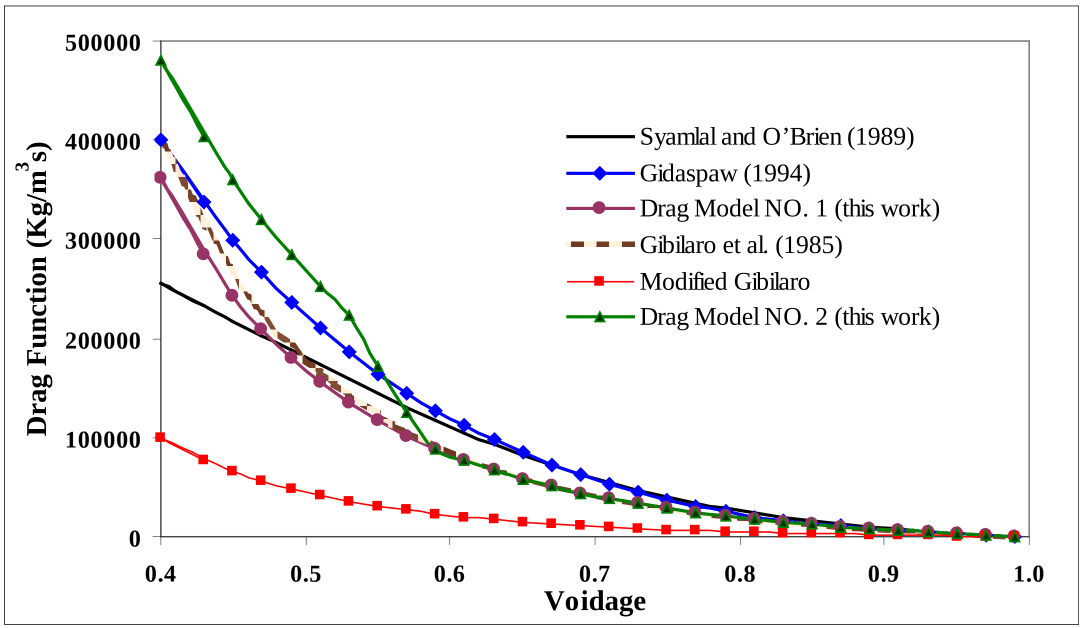
Computer Specifications

- CPU:
  - Processor: Intel Core 2 Quad, 2.83 GHz
  - Speed: 2 GHz
  - Cores: 4
- Memory:
  - RAM: 7.8 GB
  - Free swap: 4.0 GB
- Operating system:
  - Linux (openSUSE 10.3)
- Graphic card:
  - nVidia GeForce 8600 GT
- Time needed for simulating 25 s of real time:
  - 0.5 cm mesh: 40 days
  - 1 cm mesh: 13 days
  - 2 cm mesh: 7 days



CFD simulation of a bubbling fluidized bed of Geldart A particles

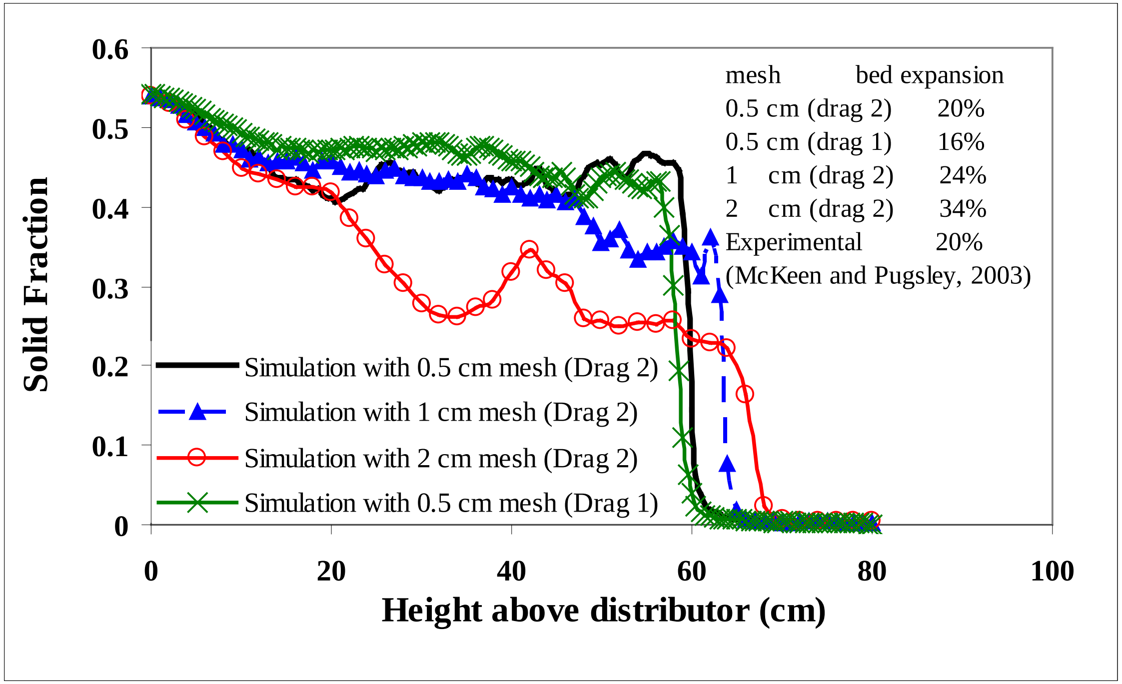
- Drag models



Model 1	$C_D = \frac{24}{Re}$	$Re < 0.5$
	$C_D = \frac{24}{Re}\left(1+0.15Re^{0.687}\right)$	$0.5 \le Re < 1000$
	$C_D = 0.44$	$Re \ge 1000$
	$D = \frac{3}{4}C_D\rho_g\theta\frac{\lvert u_g-u_p\rvert}{d_p}\varepsilon^{-1.65}$	
	$Re = \frac{\rho_g\varepsilon d_p\lvert u_g-u_p\rvert}{\mu_g}$	
Model 2	$C_D = \frac{24}{Re}$	$Re < 0.5$
	$C_D = \frac{24}{Re}\left(1+0.15Re^{0.687}\right)$	$0.5 \le Re < 1000$
	$C_D = 0.44$	$Re \ge 1000$
	$D_1 = \frac{3}{4}C_D\rho_g\theta\frac{\lvert u_g-u_p\rvert}{d_p}\varepsilon^{-1.65}$	
	$D_2 = \left(\frac{180\theta}{Re}+2\right)\frac{\lvert u_g-u_p\rvert}{d_p}\rho_g\theta$	
	$Re = \frac{\rho_g\varepsilon d_p\lvert u_g-u_p\rvert}{\mu_g}$	
	$D = D_1$	$\theta < 0.75\theta_{CP}$
	$D = \frac{\theta-0.85\theta_{CP}}{0.85\theta_{CP}-0.75\theta_{CP}}\left(D_2-D_1\right)+D_1$	$0.75\theta_{CP} \le \theta \le 0.85\theta_{CP}$
	$D = D_2$	$\theta > 0.85\theta_{CP}$

CFD simulation of a bubbling fluidized bed of Geldart A particles

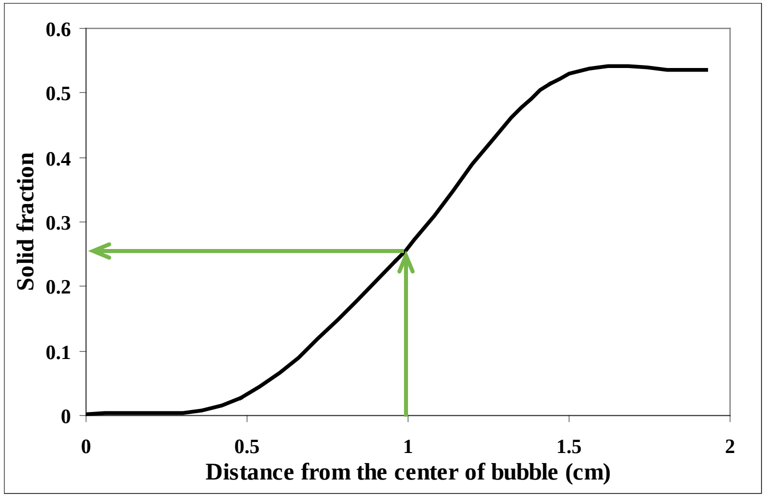
- Results and discussions
  - Bed expansion

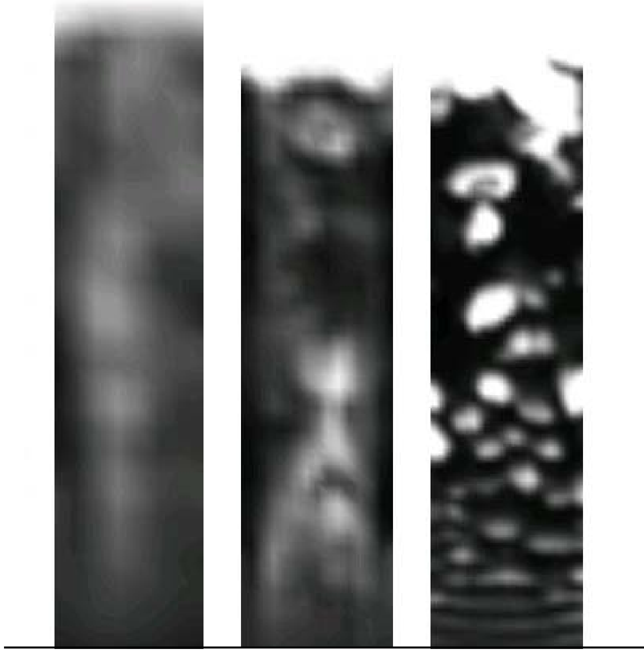


CFD simulation of a bubbling fluidized bed of Geldart A particles

- Results and discussions
  - Detection of bubbles
  - Bubble size and velocity:
    - Global image thresholding using Otsu's method (1979): An optimal threshold is automatically selected by a discriminant criterion in order to maximize the separability of the resultant classes in gray levels.

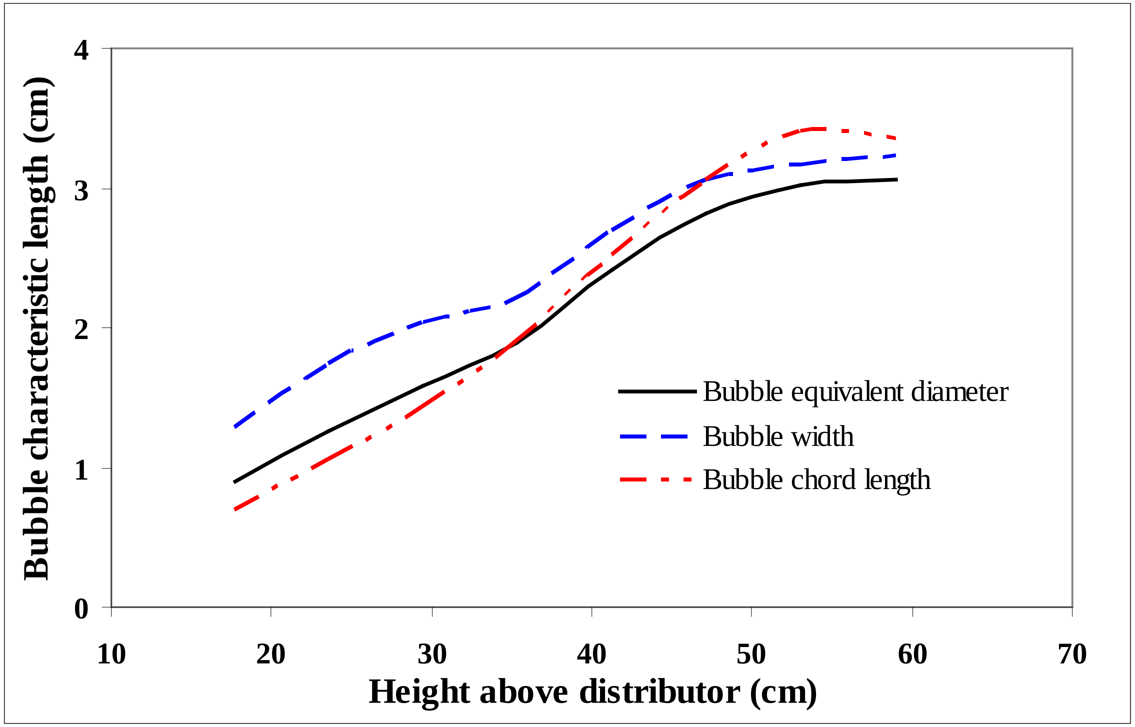
  - Bubble average solid fraction
    - Bubble boundary detection based on Harlow and Amsden (1975) suggestion: Bubbles should be seen in the context of their surroundings. Thus, boundary of each bubble has been found separately.





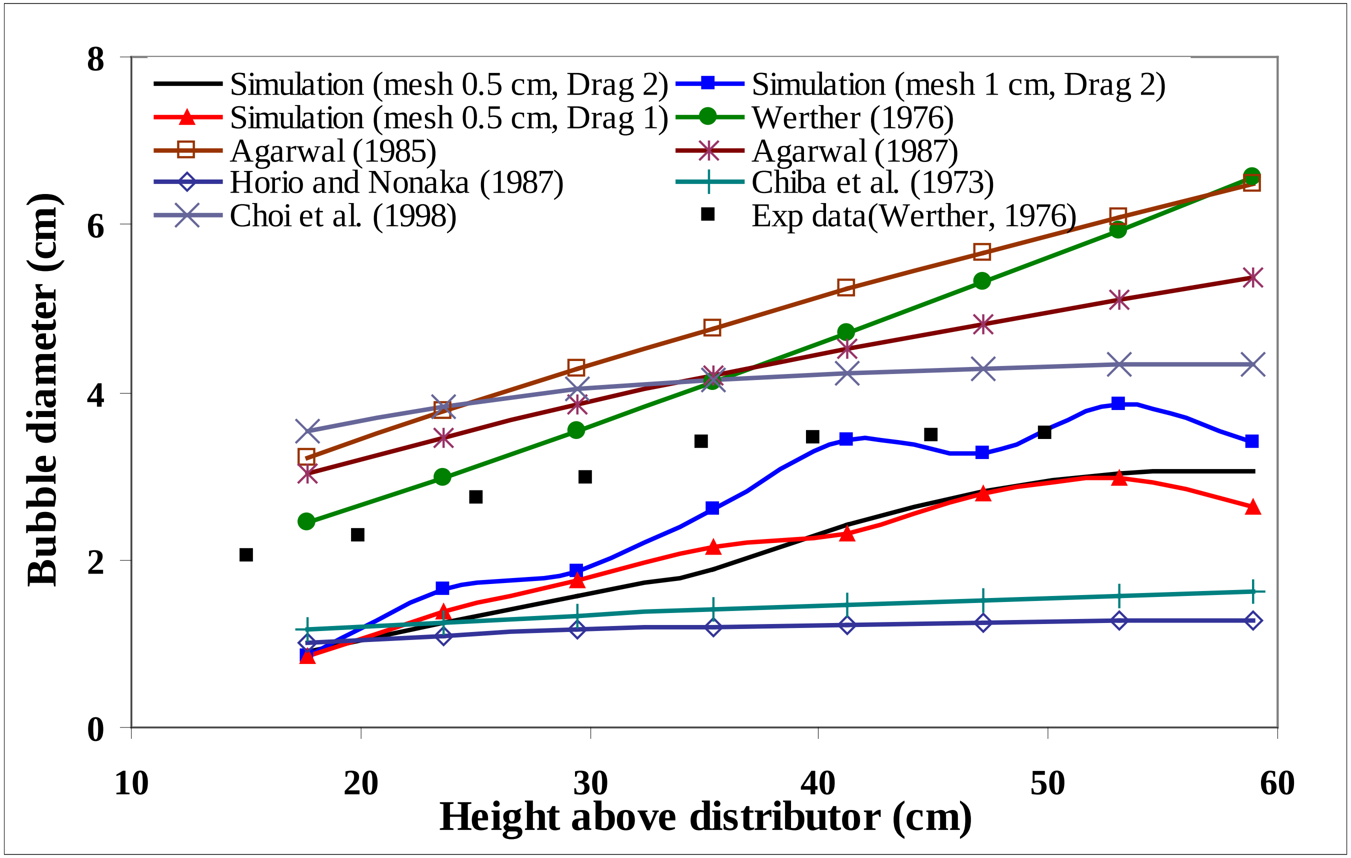
CFD simulation of a bubbling fluidized bed of Geldart A particles

- Results and discussions
  - Bubble shape



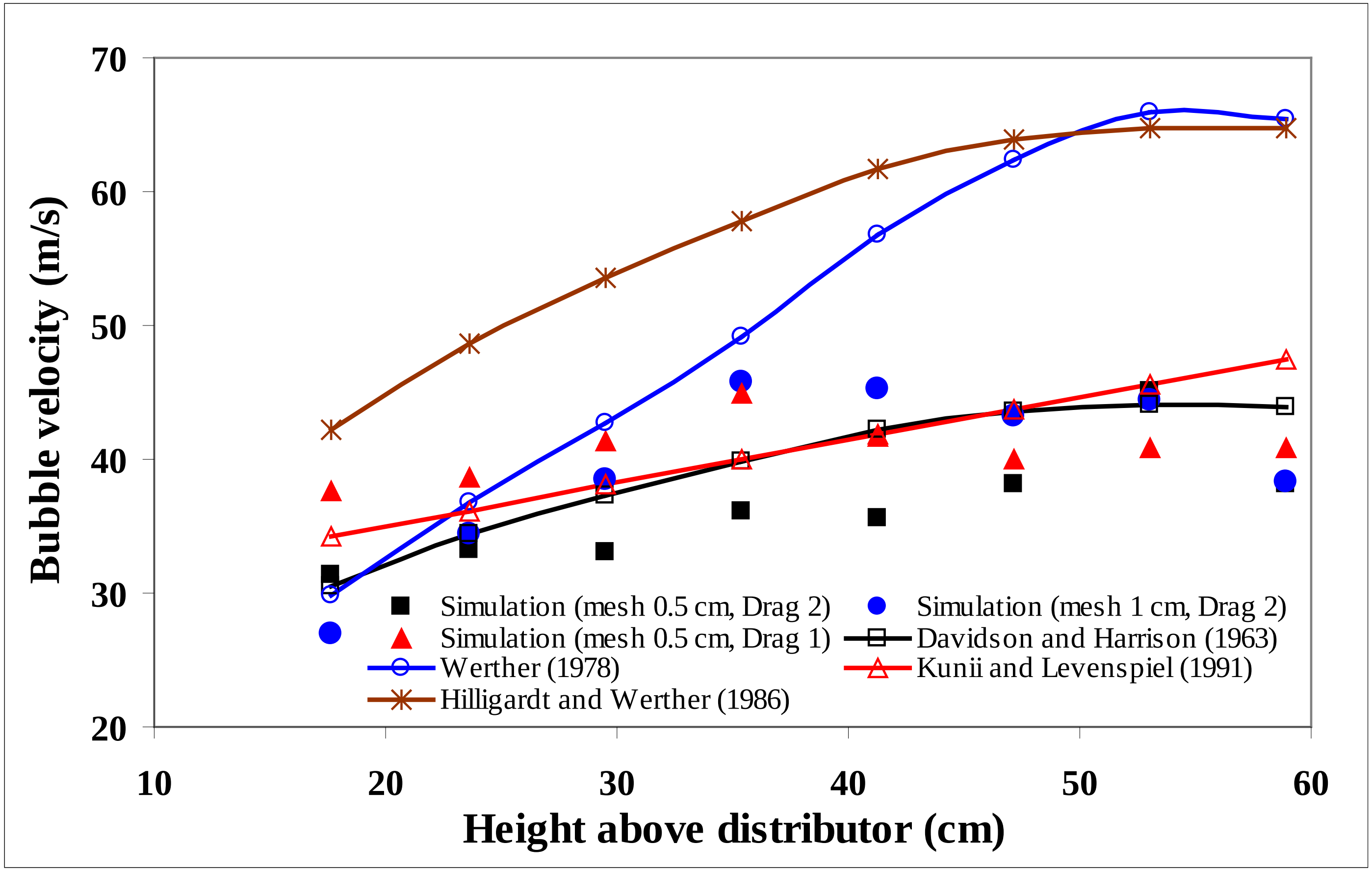
CFD simulation of a bubbling fluidized bed of Geldart A particles

- Results and discussions
  - Bubble size



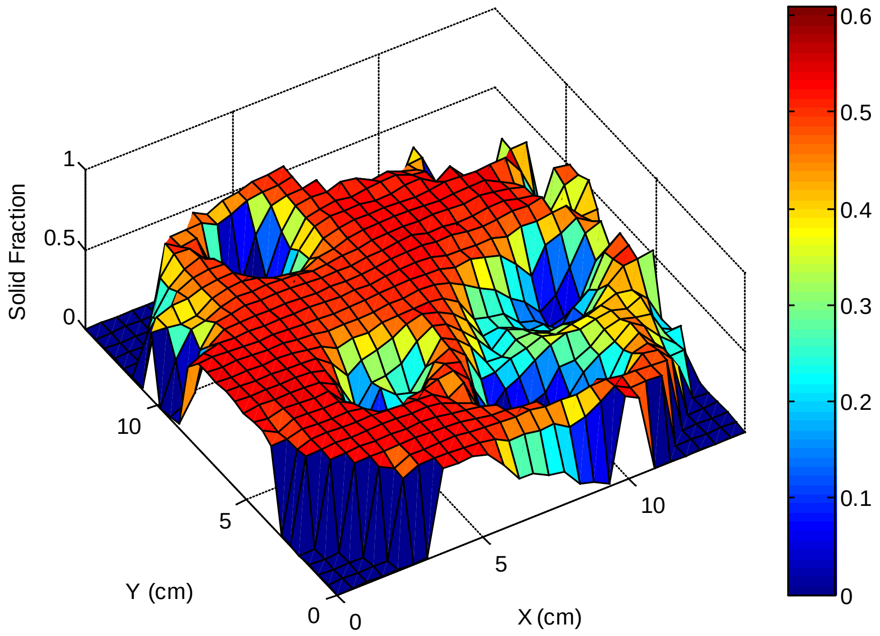
CFD simulation of a bubbling fluidized bed of Geldart A particles

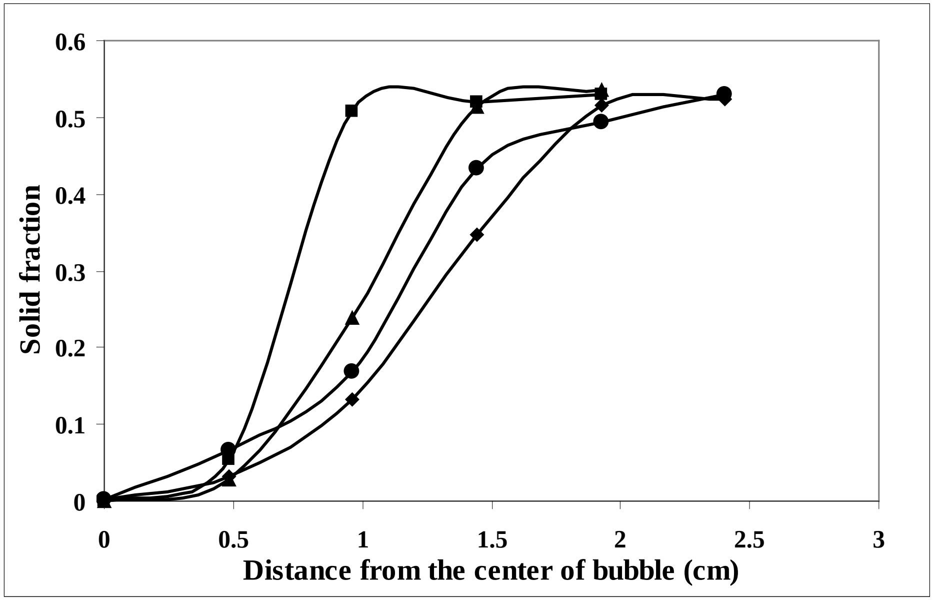
- Results and discussions
  - Bubble velocity



CFD simulation of a bubbling fluidized bed of Geldart A particles

- Results and discussions
  - Bubble solid fraction

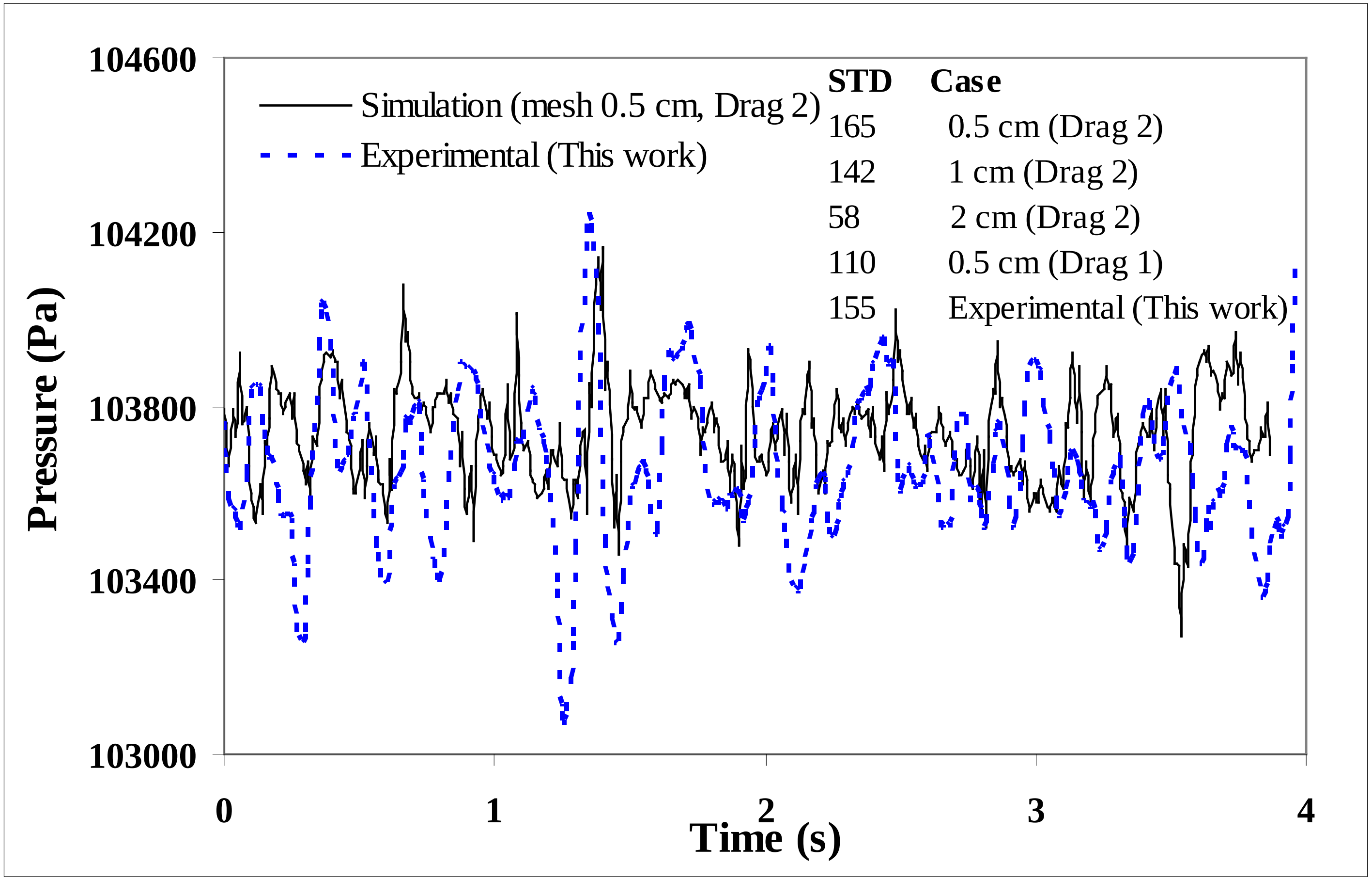




	mesh 0.5 cm Drag NO. 2	mesh 1 cm Drag NO. 2	mesh 2 cm Drag NO. 2	mesh 0.5 cm Drag NO. 1	Correlation of Cui et al. (2000)
Bubble voidage	0.667	0.710	0.640	0.767	0.687
Difference with the correlation (%)	-2.91	3.34	-6.64	11.64	

CFD simulation of a bubbling fluidized bed of Geldart A particles

- Results and discussions
  - Dynamic characteristics



CFD simulation of a bubbling fluidized bed of Geldart A particles

Conclusion

- Our earlier work with MFIX successfully validated by comparison with experimental data, but required reduction of drag force
- Presentations at this Workshop have also presented reduced drag relationships
- Multiphase PIC approach as implemented in Barracuda compared favorably with data without modification of the drag model; also allows introduction of particle size distribution and 3D with reasonable computation times
- Not clear how or if interparticle forces and clustering are captured with the MP-PIC approach

Thank you

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http://www.engr.usask.ca/flask/