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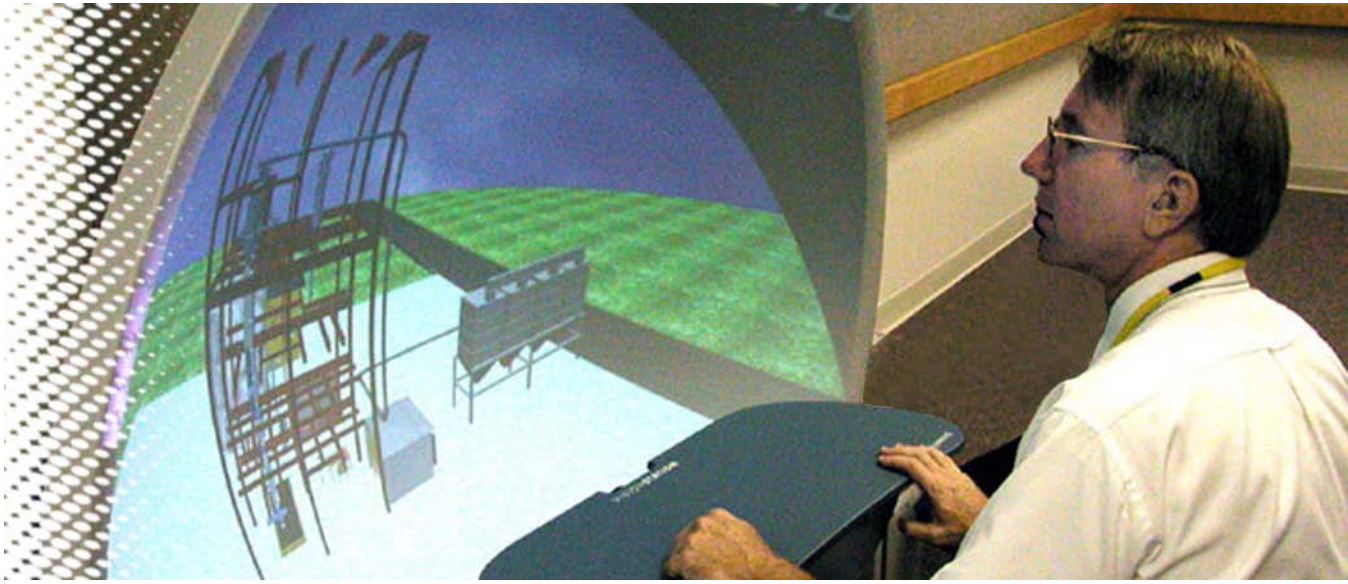

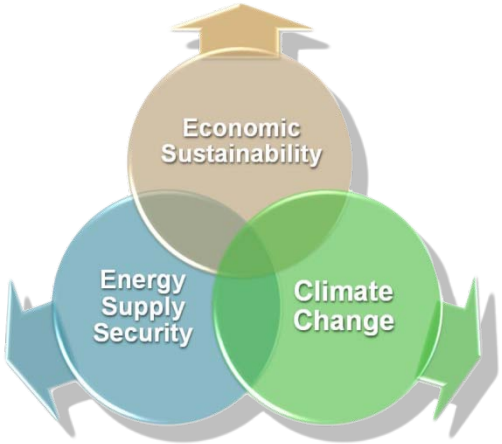

2D versus 3D CFD Simulations of Circulating Fluidized Bed Risers

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U.S. DEPARTMENT OF ENERGY

Introduction

- **Expensive computational cost of riser simulation**
  - Unsteady, multi-scale (spatial and temporal)
  - Typical scale (tall even in lab scale)

- **Simplifications used in riser simulations**
  - Isolating the region of interest (riser/downer only)
  - Decoupling of multiple physics (hydrodynamics only)
  - Sub-grid model, EMMS
  - Periodic domain (fully developed)
  - Axi-symmetric assumption (steady flow modeling)
  - 2D flow assumption

Introduction cont'd

- **2D flow assumption**
  - A plane through the axis of cylindrical column
  - Greatly reduce the computational cost
  - Widely used in fluidized bed simulations (bubbling, turbulent, slugging, circulating …)
  - Extensive validations in literature

- **For bubbling beds, it has been suggested that 2D simulation is only good for qualitative study, 3D simulation is needed for quantitative prediction**

Objective

- **To investigate the differences between 2D and 3D simulations of several CFB risers**

Numerical Model

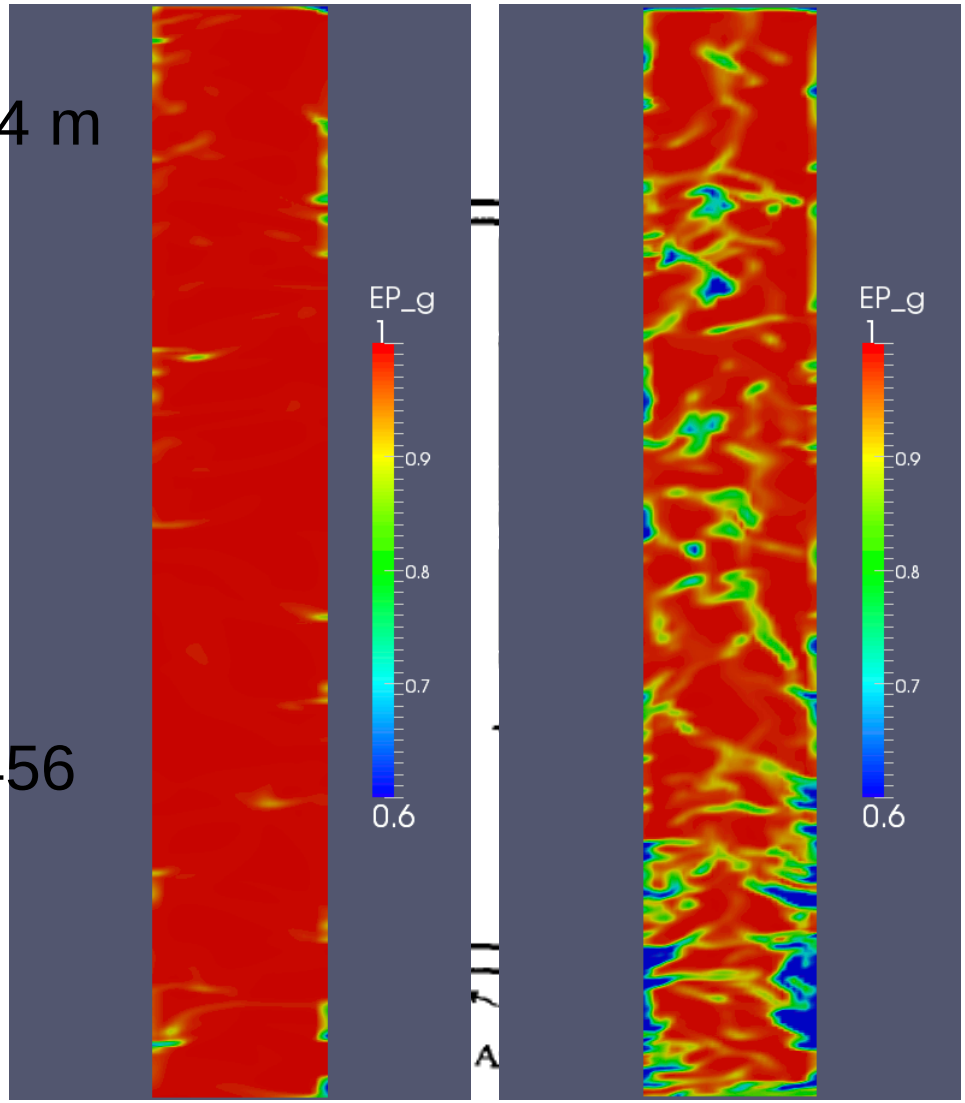
- **CFD Solver**
  - TFM (Eulerian-Eulerian)
  - MFIX, FLUENT

- **Riser Configuration**
  - Case 1: Riser with square cross-section
  - Case 2: Cylindrical riser with side inlet and outlet
  - Case 3: Cylindrical riser with axi-symmetrical inlets

- **Flow Assumption**
  - Riser-only simulation
  - Cold flow model

Case 1: Square Riser

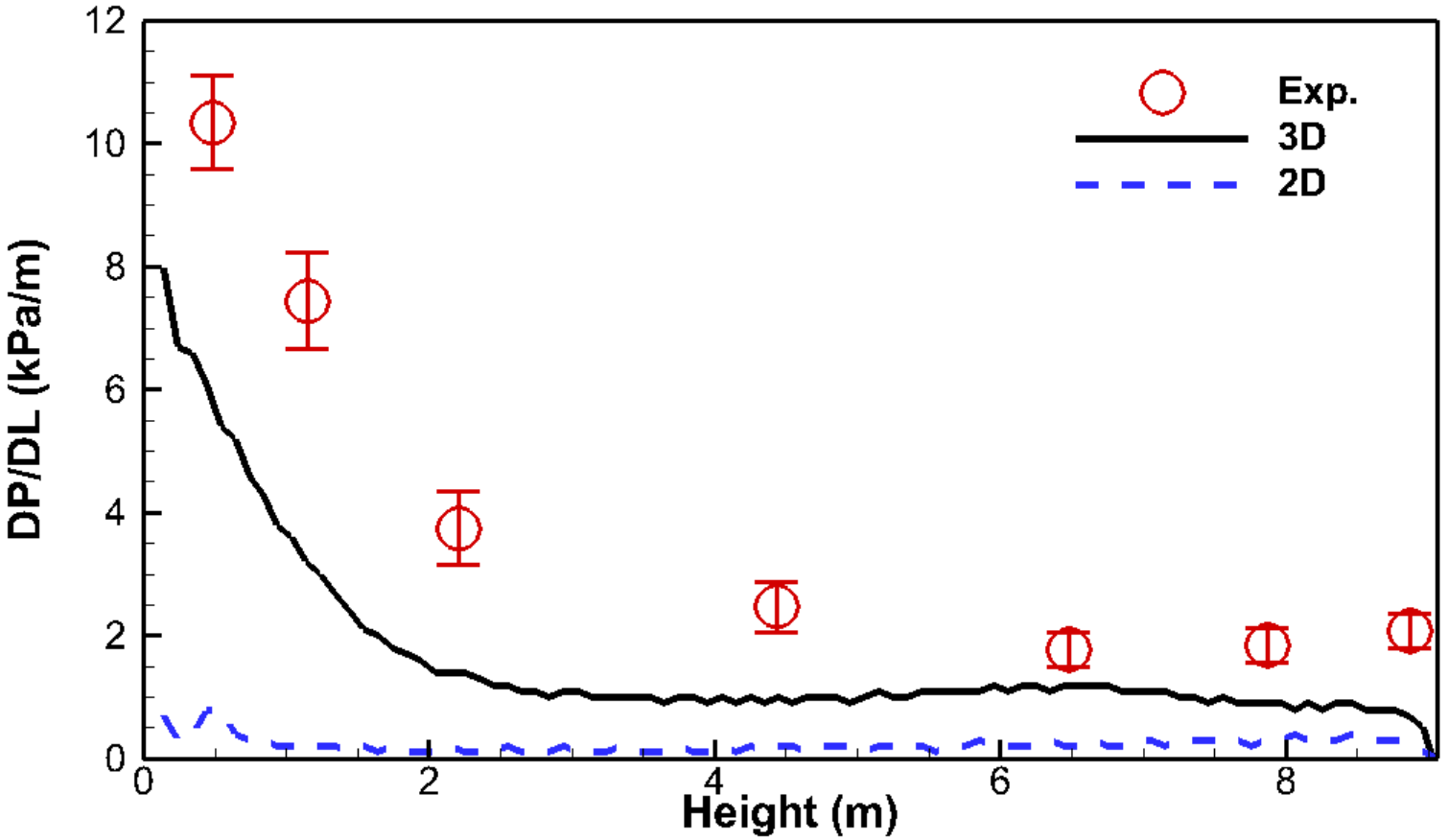
- **Flow Conditions**
  - Size: 0.146x0.146x9.14 m
  - d_p: **213 µm**
  - ρ_p: 2640 kg/m^3
  - U_g: 5.5 m/s
  - G_s: 40 kg/m^{2}s
- **Numerical Setup**
  - Grid: 30x456, 30x30x456
  - Time: 100 s
  - Average: 60 s



Zhou et al. 1994, CES

Case 1: Square Riser cont'd

- **Pressure Gradient**

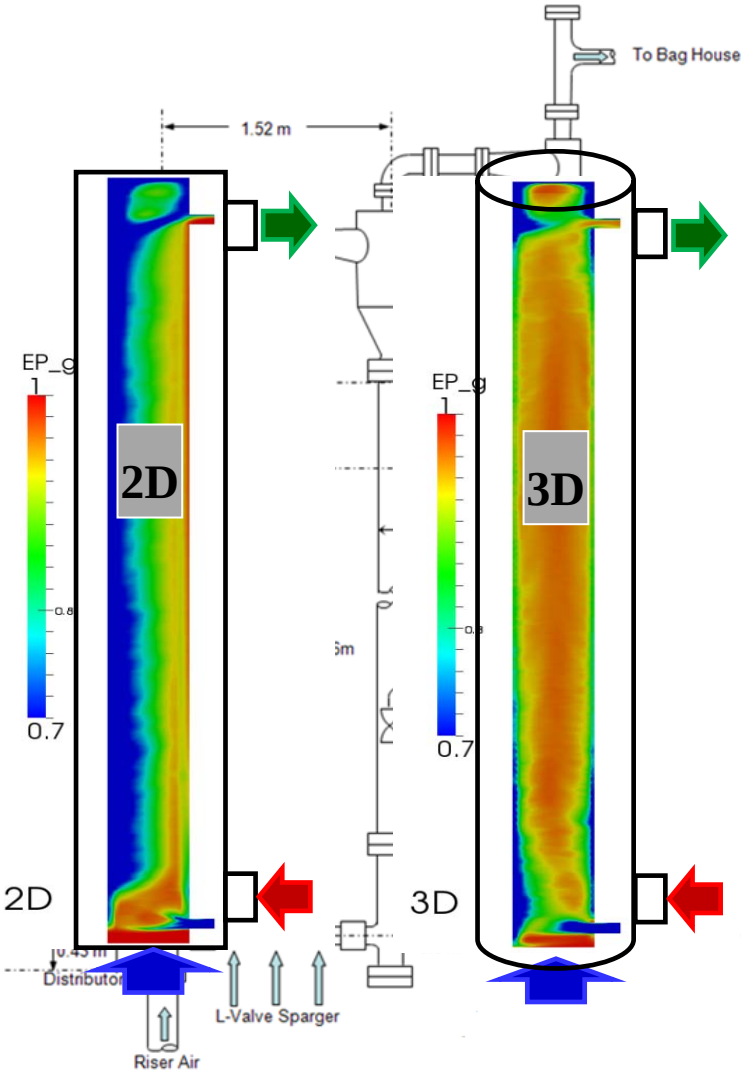


2D simulation under-predicts pressure gradient by 3D simulation.
3D geometry is a basic requirement to accurately simulate this CFB riser

Li et al. 2011, CFB X

Case 2: NETL B22 Riser

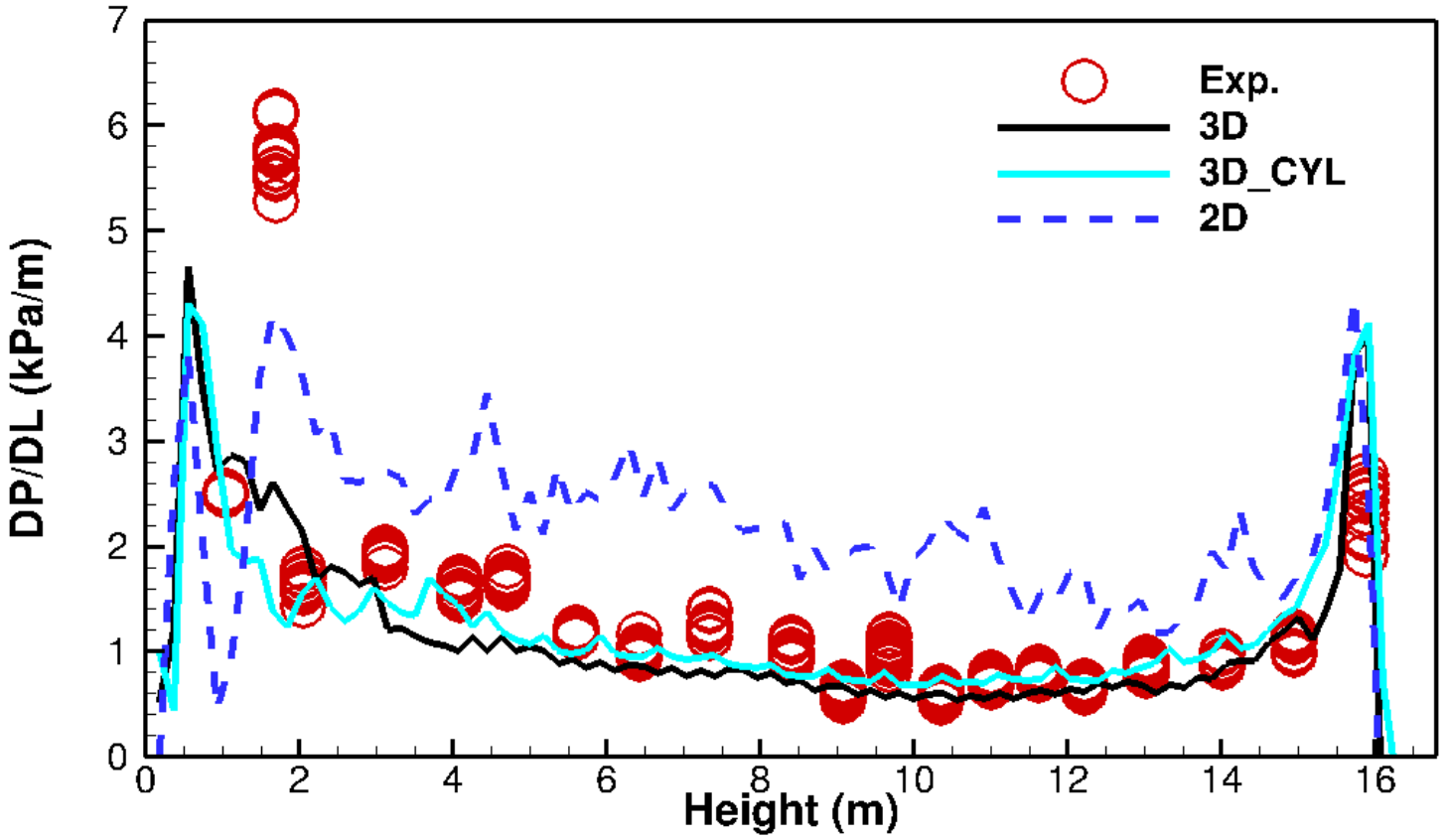
- **Flow Conditions**
  - Size: Φ0.3x16.8 m
  - d_p: **802 μm**
  - ρ_p: 863 kg/m^3
  - $U_{g,bt}$: 7.58 m/s
  - G_s: 193 kg/m^{2}s
- **Numerical Setup**
  - Grid: 25x1050, 19x25x1050
  - Time: 80s (2D); 60s (3D)
  - Average: 60s (2D); 40s (3D)
  - Cut-cell (3D)



Shadle et al. 2011, CFB X

Case 2: NETL B22 Riser cont'd

- **Pressure Gradient**

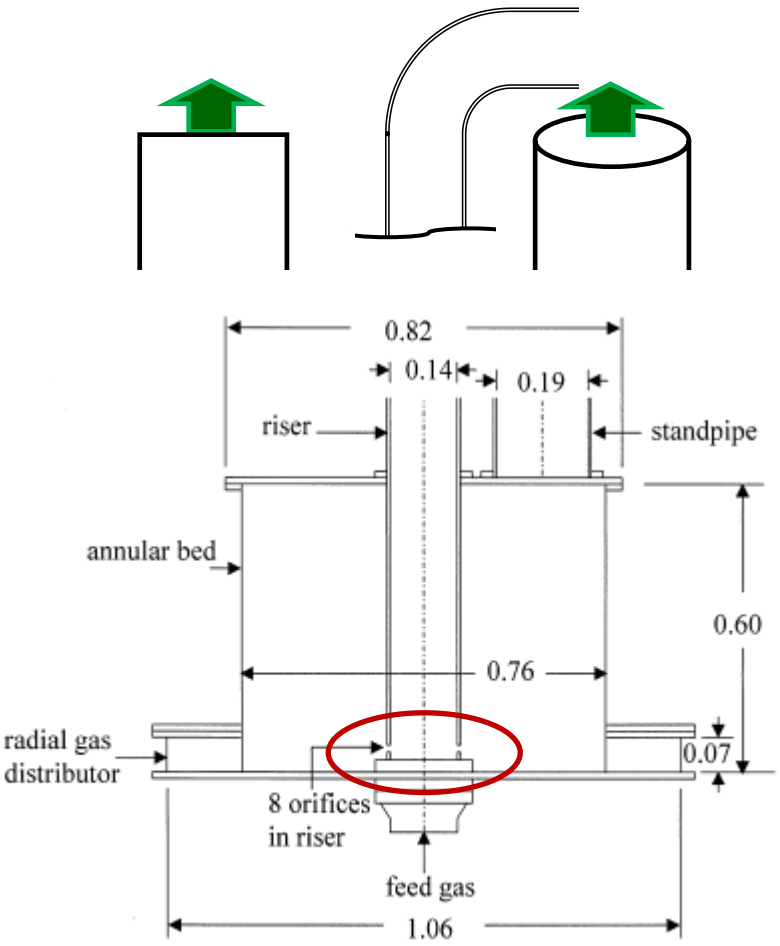


2D simulation over-predicts pressure gradient by 3D simulation & experiment

Li et al. 2012, Submitted

Case 3: Malcus et al.'s Riser

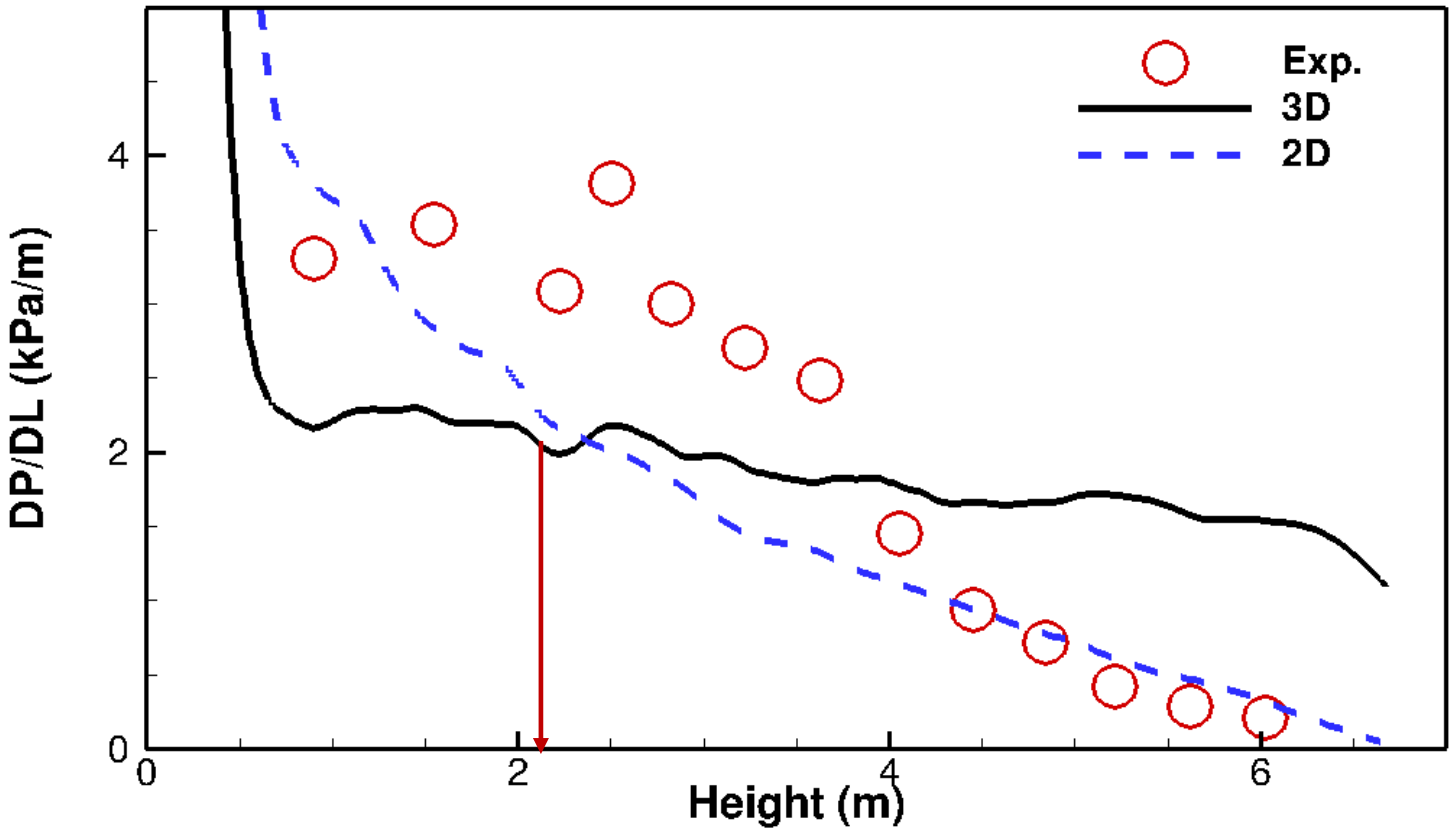
- **Flow Conditions**
  - Size: Φ0.14x7 m
  - d_p: **89 μm**
  - ρ_p: 1740 kg/m^3
  - U_g: 4.7 m/s
  - G_s: 302 kg/m^{2}s
- **Numerical Setup**
  - Grid: 10K, 185K
  - Time: 40 s
  - Average: 20 s
  - FLUENT



Malcus et al. 2000, CES

Case 3: Malcus et al.'s Riser cont'd

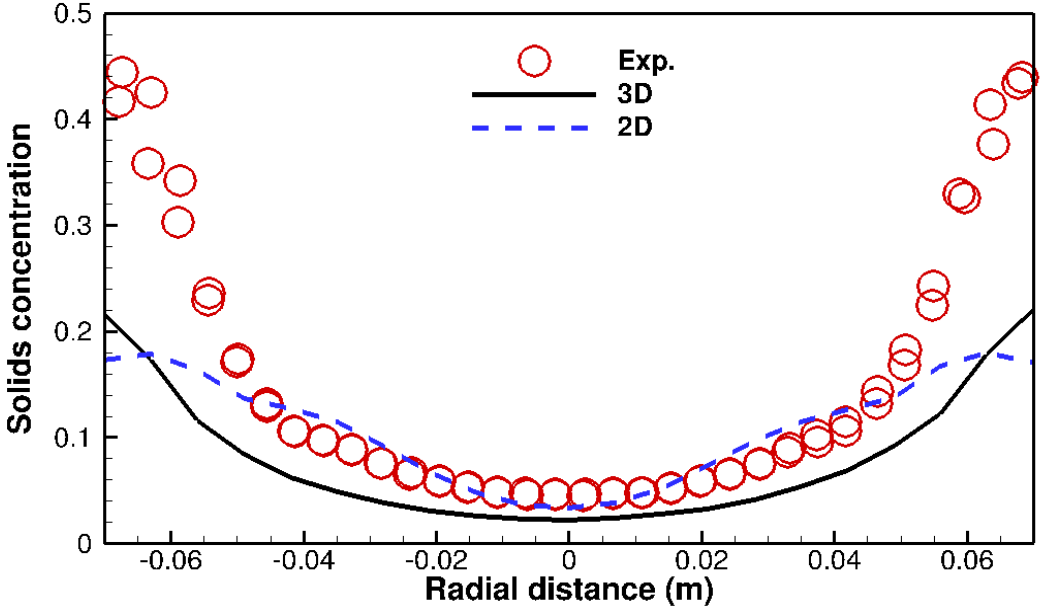
- **Pressure Gradient**



Significant differences between 2D & 3D simulations of this axi-symmetric system

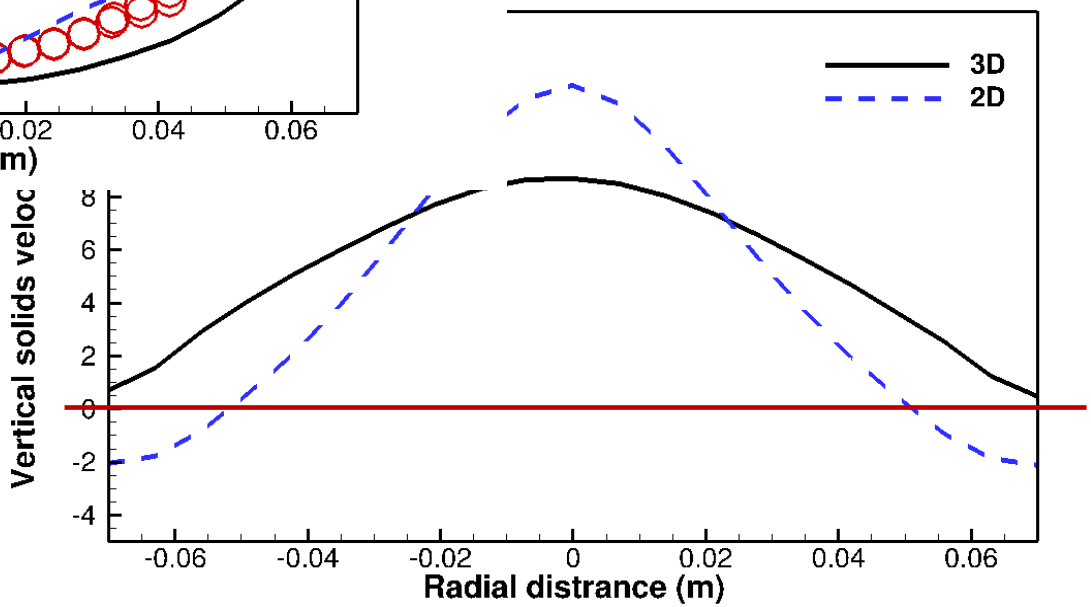
Case 3: Malcus et al.'s Riser cont'd

- **Radial Profiles**



Radial profiles of mean (left) solids concentration (right) vertical solids velocity at the height of 2.1m

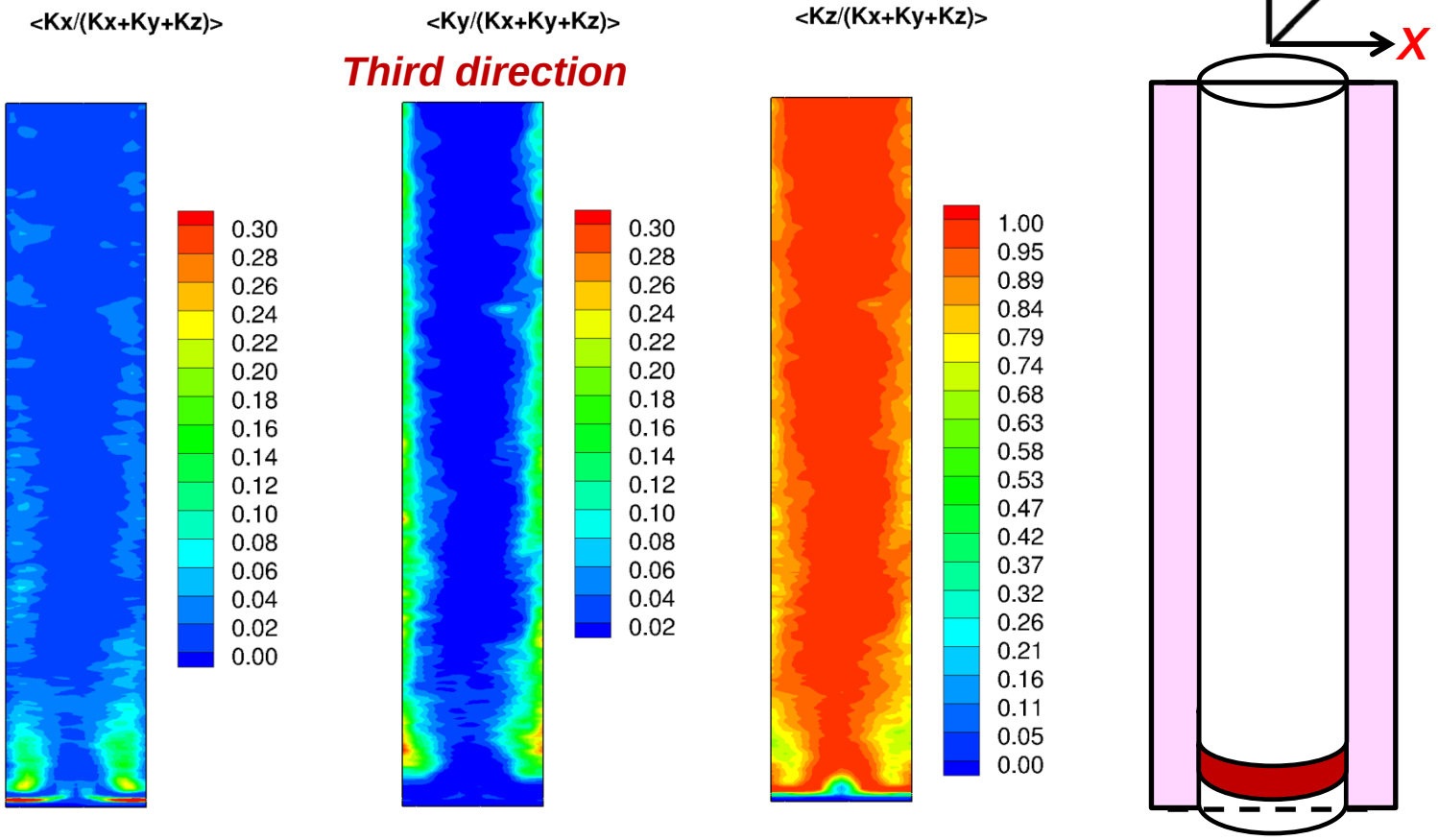
Similar solid holdups but quite different radial solids distributions and velocities



Discussion

- **Is movement in the third direction negligible?**
  - No, especially close to wall

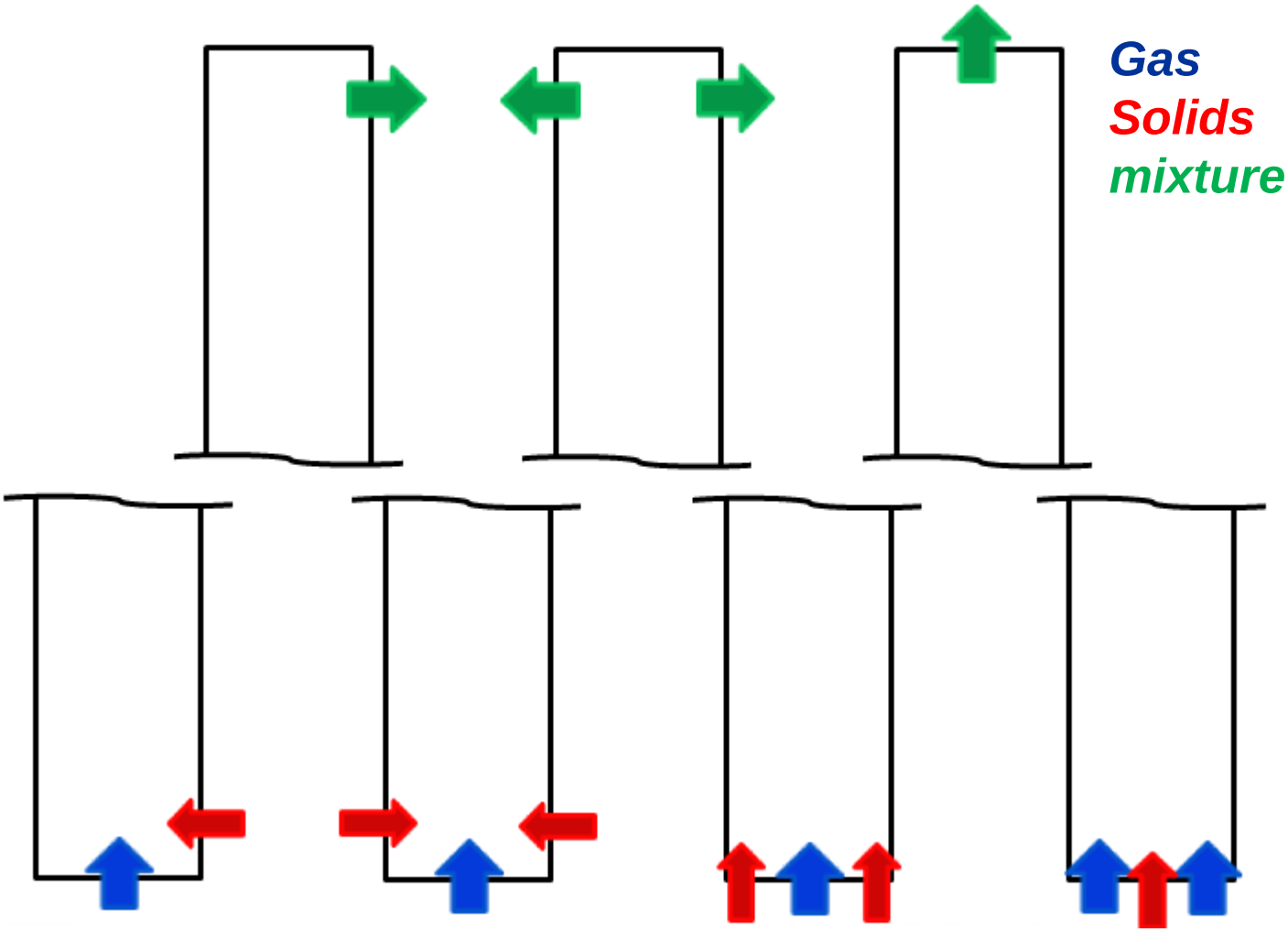
Kx=1/2ρu²; Ky=1/2ρv² ; Kz=1/2ρw²



Kinetic energy components from different directions in the X-Z plane

Discussion cont'd

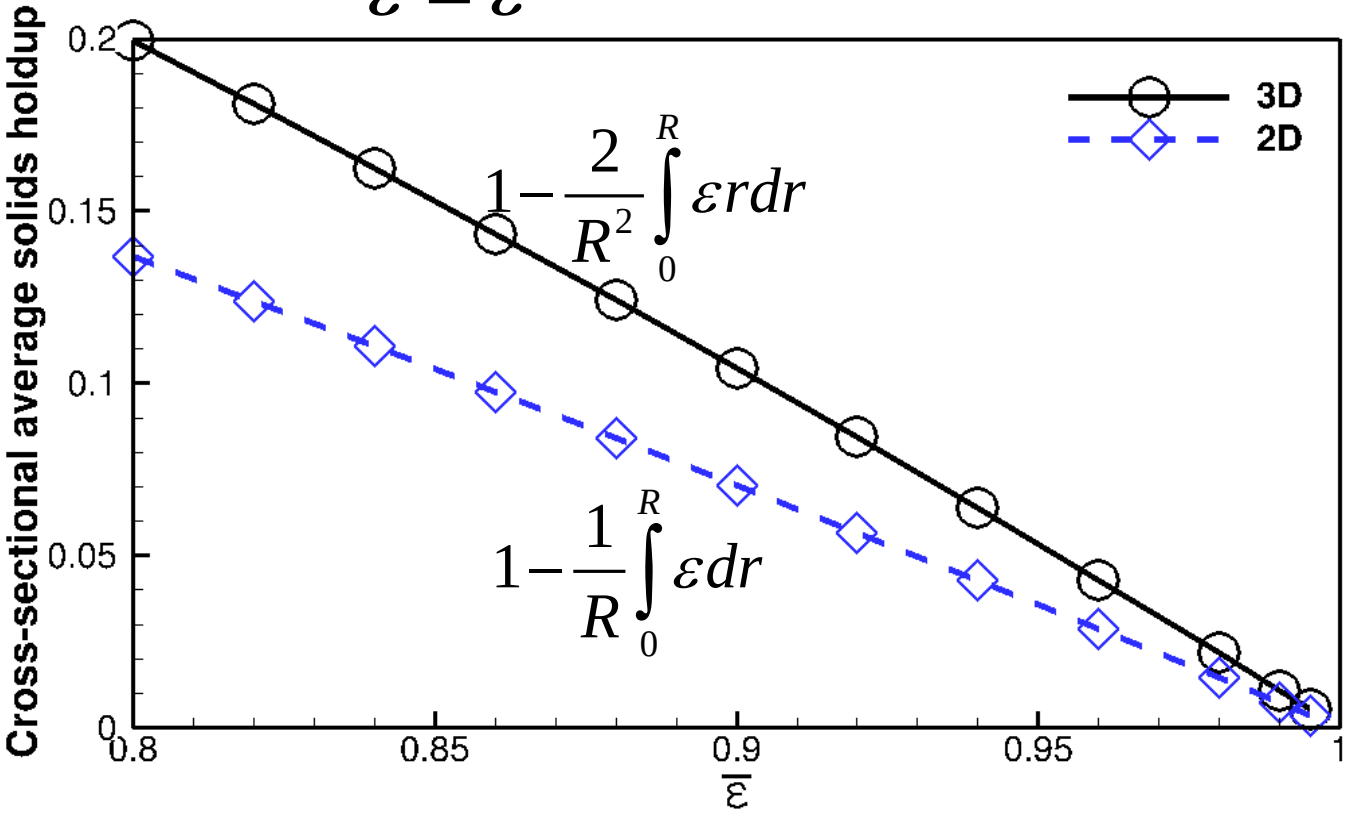
- **Hard to impose inlet and outlet boundaries in 2D**



Discussion cont'd

- **Not straightforward to compare 2D results to 3D data**

$$\varepsilon = \overline{\varepsilon}^{\left[0.191+(r/R)^{2.5}+3(r/R)^{11}\right]}$$



It is impossible to match both axial solids holdup and radial solids concentration profiles for 2D simulation

Zhang et al. 1991, CES

Conclusions

- As far as axial pressure gradient is concerned, 2D simulation cannot predict reasonable agreement to 3D simulation results for cases studied.
- For 2D simulation, it is impossible to match both axial solids holdup and radial solids concentration profiles to 3D data.
- The 3D numerical simulation is needed to accurately capture the quantitative flow behavior in CFB risers.
- The 2D numerical simulation probably can only be used for qualitative studies.

Acknowledgement

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Disclaimer