

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

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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

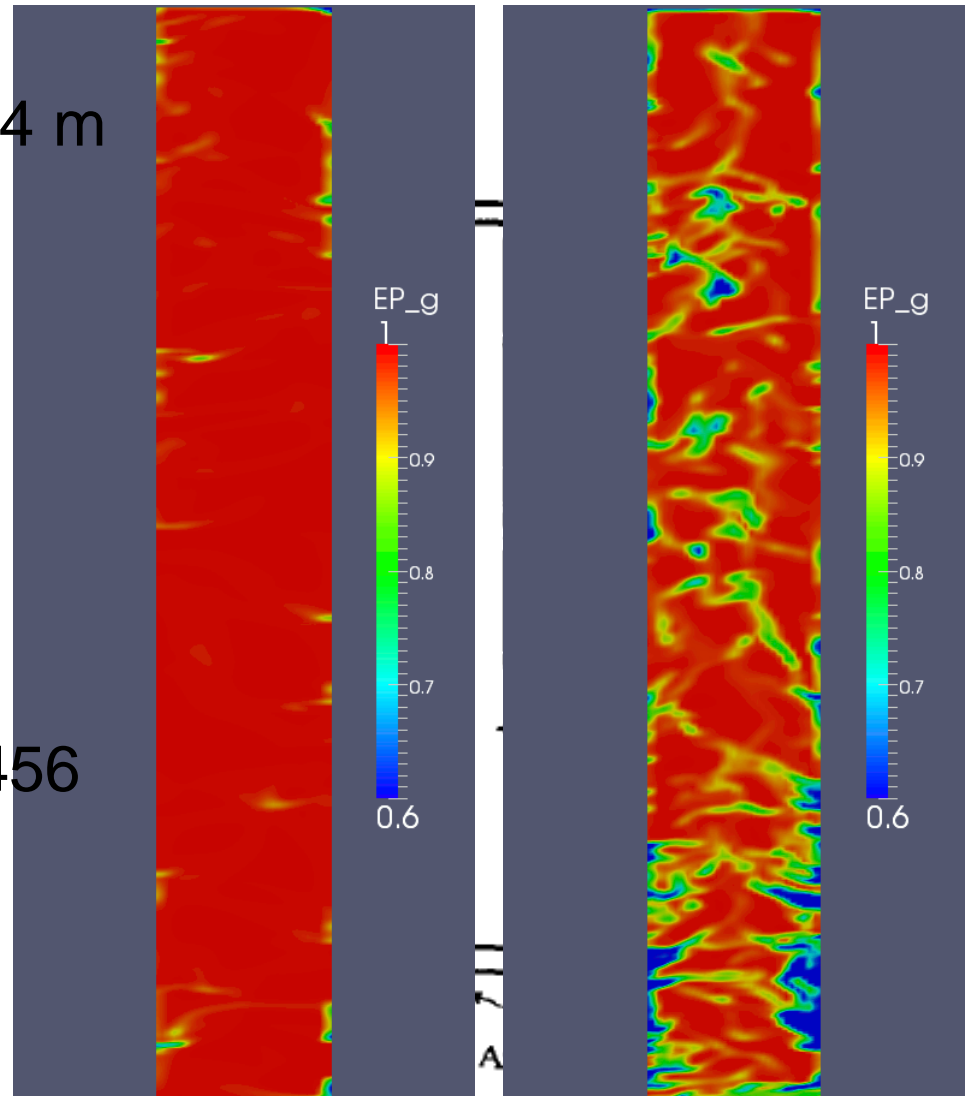
Case 1: Square Riser

- **Flow Conditions**

- Size: 0.146x0.146x9.14 m
- d_p : **213 μm**
- ρ_p : 2640 kg/m³
- U_g : 5.5 m/s
- G_s : 40 kg/m²s

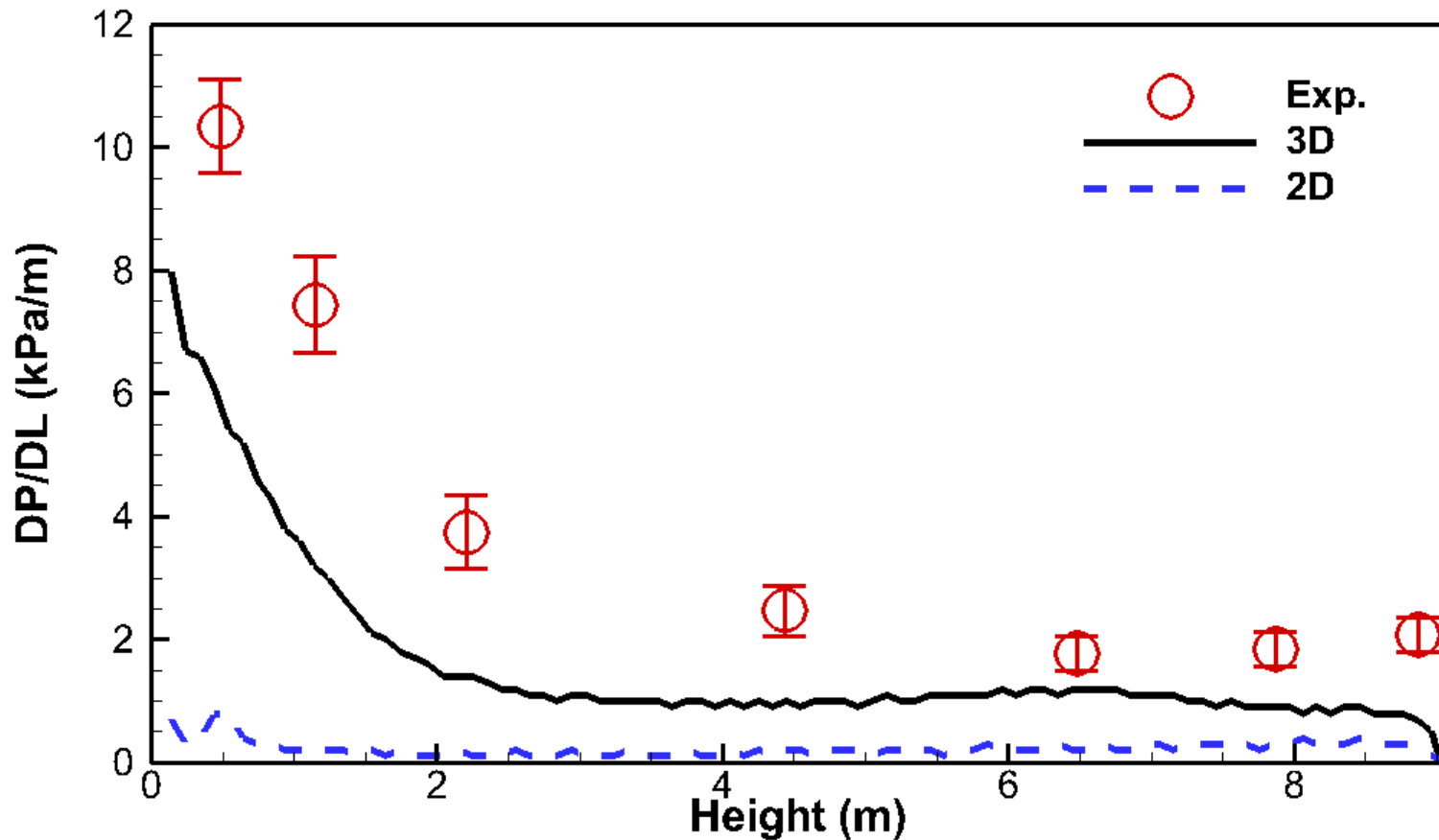
- **Numerical Setup**

- Grid: 30x456, 30x30x456
- Time: 100 s
- Average: 60 s



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*

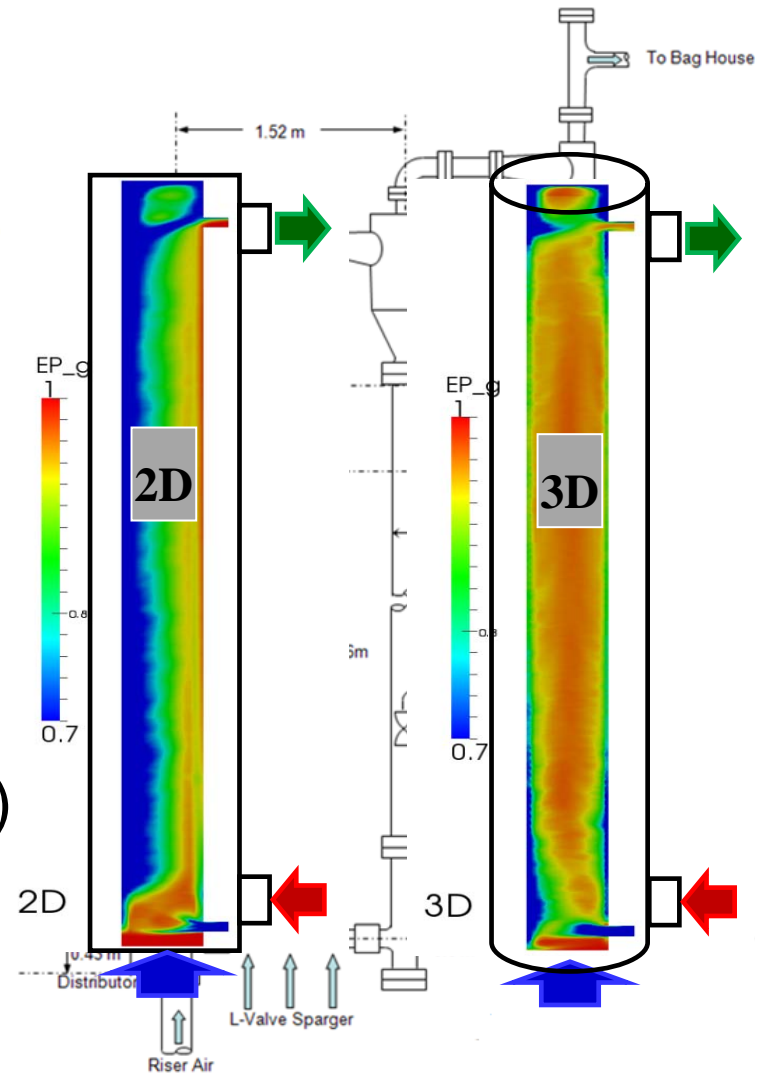
Case 2: NETL B22 Riser

- **Flow Conditions**

- Size: $\Phi 0.3 \times 16.8$ m
- d_p : **802 μm**
- ρ_p : 863 kg/m³
- $U_{g,bt}$: 7.58 m/s
- G_s : 193 kg/m²s

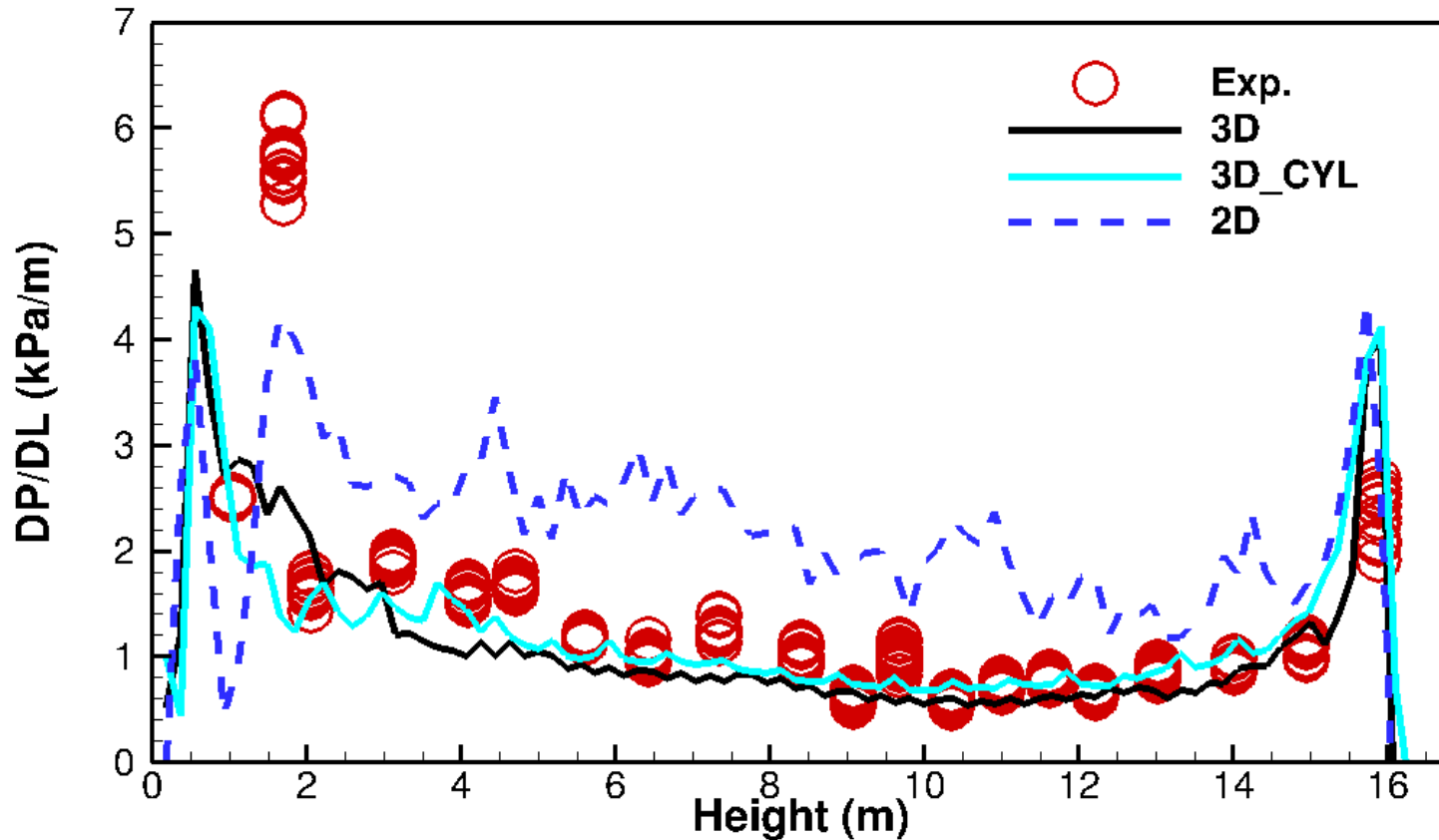
- **Numerical Setup**

- Grid: 25x1050, 19x25x1050
- Time: 80s (2D); 60s (3D)
- Average: 60s (2D); 40s (3D)
- Cut-cell (3D)



Case 2: NETL B22 Riser cont'd

- Pressure Gradient



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

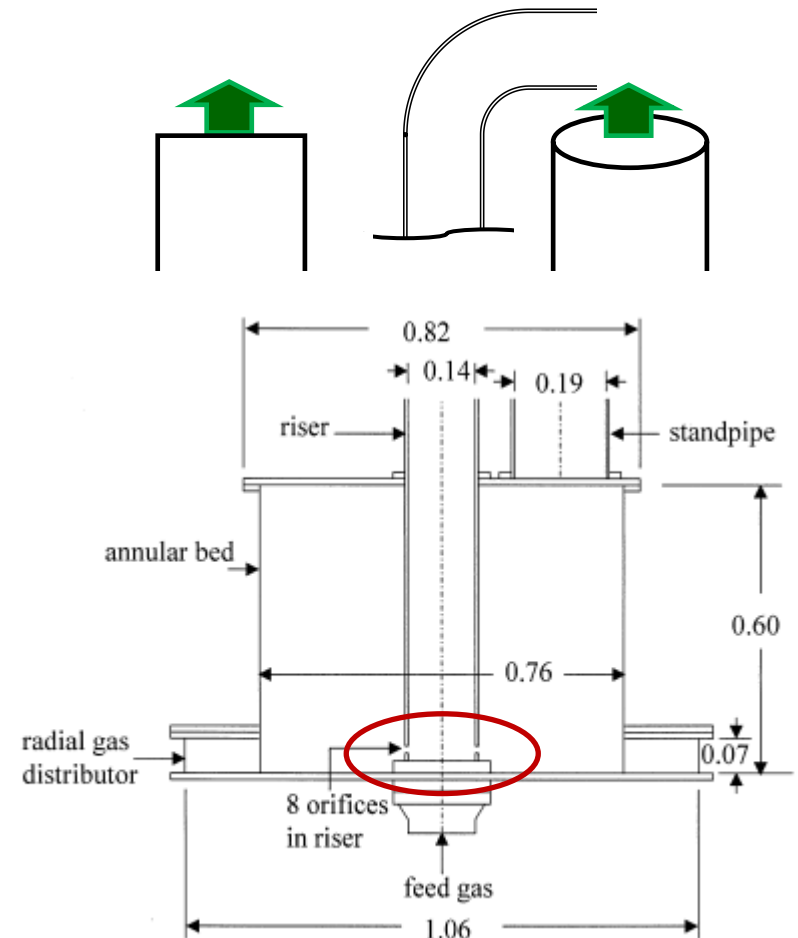
Case 3: Malcus et al.'s Riser

- **Flow Conditions**

- Size: $\Phi 0.14 \times 7$ m
- d_p : **89 μm**
- ρ_p : 1740 kg/m³
- U_g : 4.7 m/s
- G_s : 302 kg/m²s

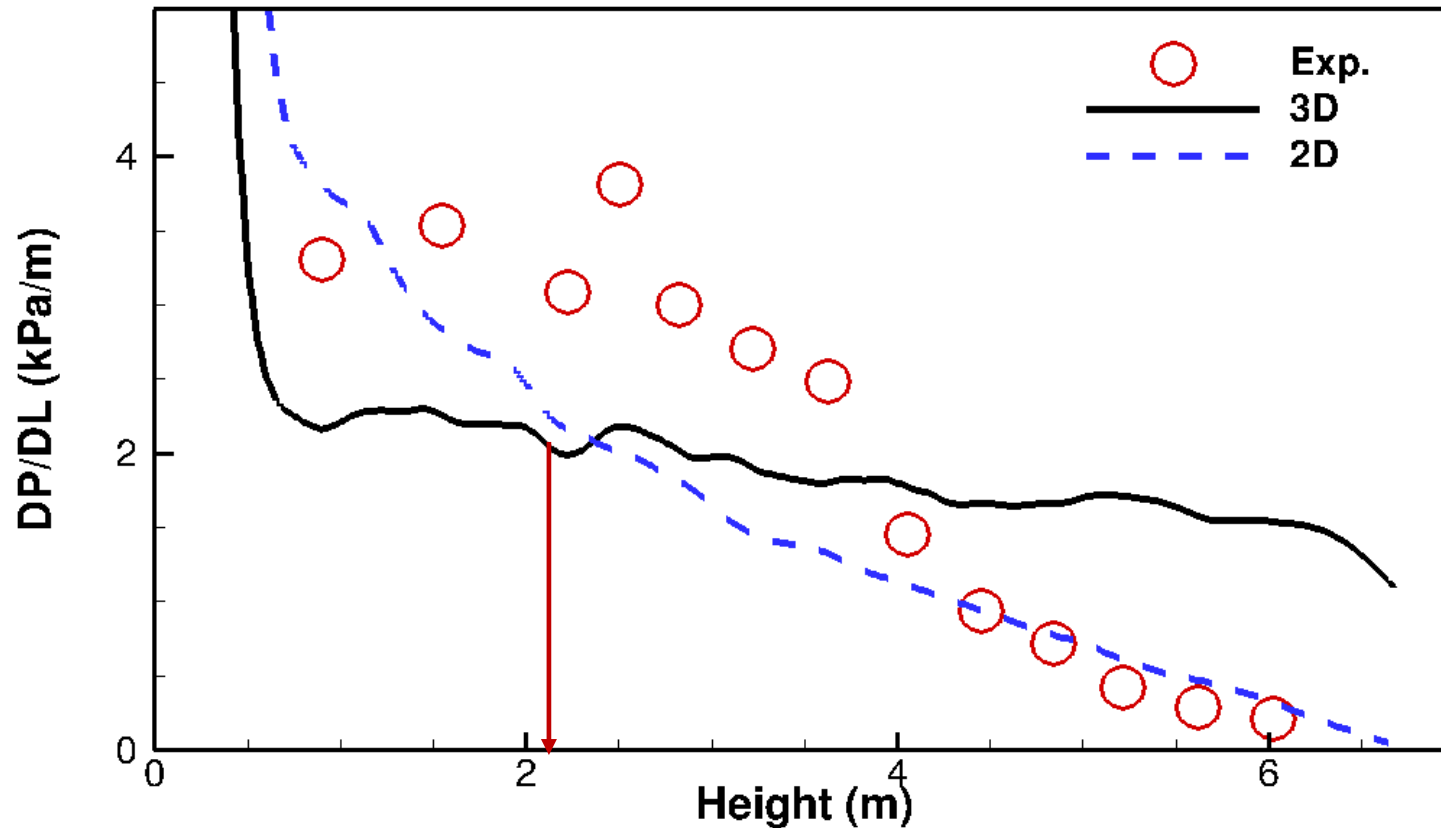
- **Numerical Setup**

- Grid: 10K, 185K
- Time: 40 s
- Average: 20 s
- FLUENT



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

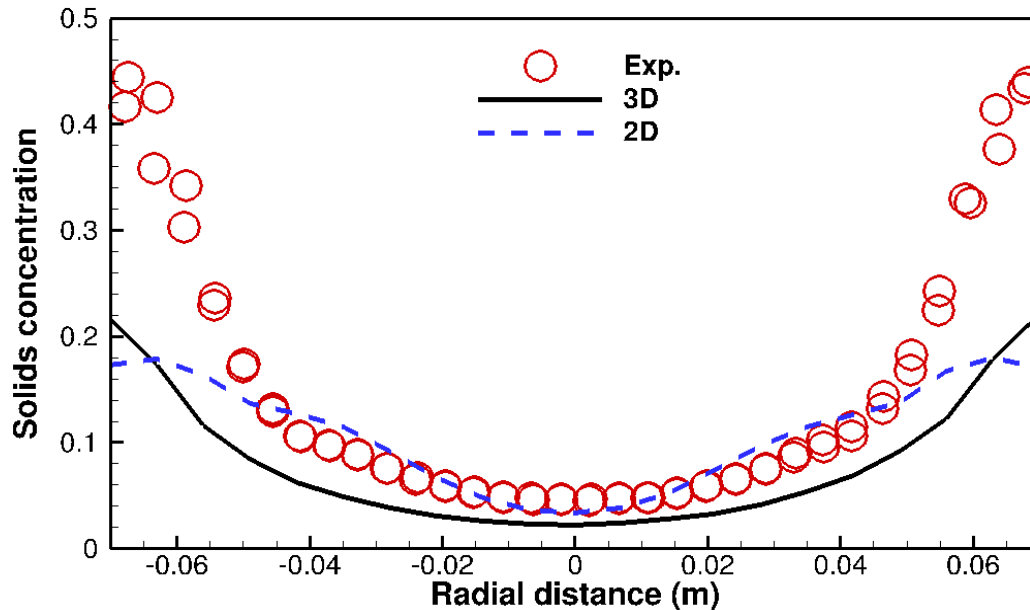
- Pressure Gradient



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

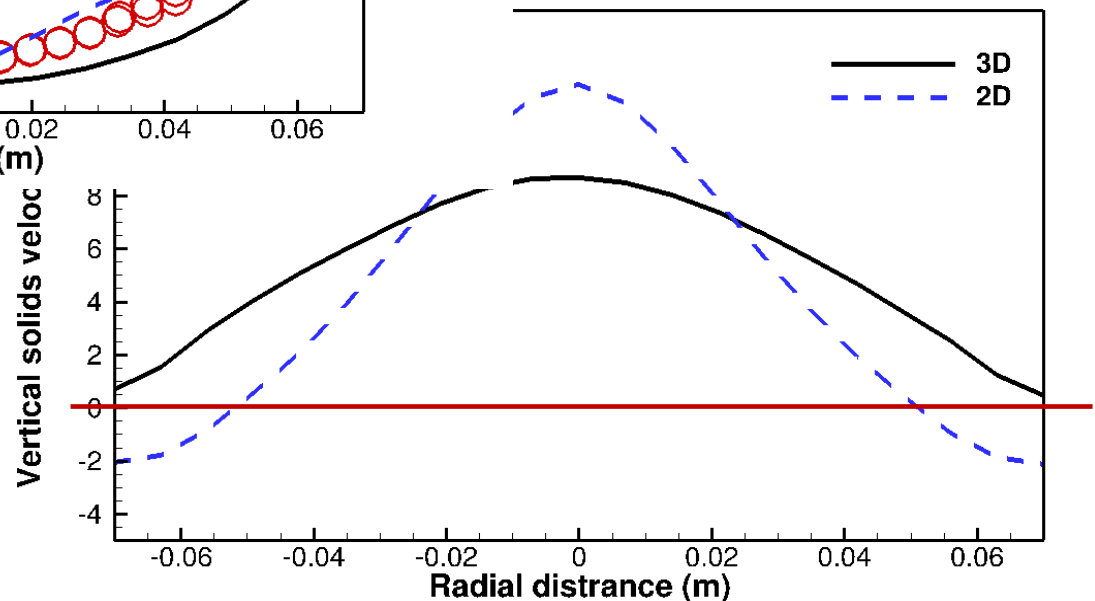
Case 3: Malcus et al.'s Riser cont'd

• Radial Profiles



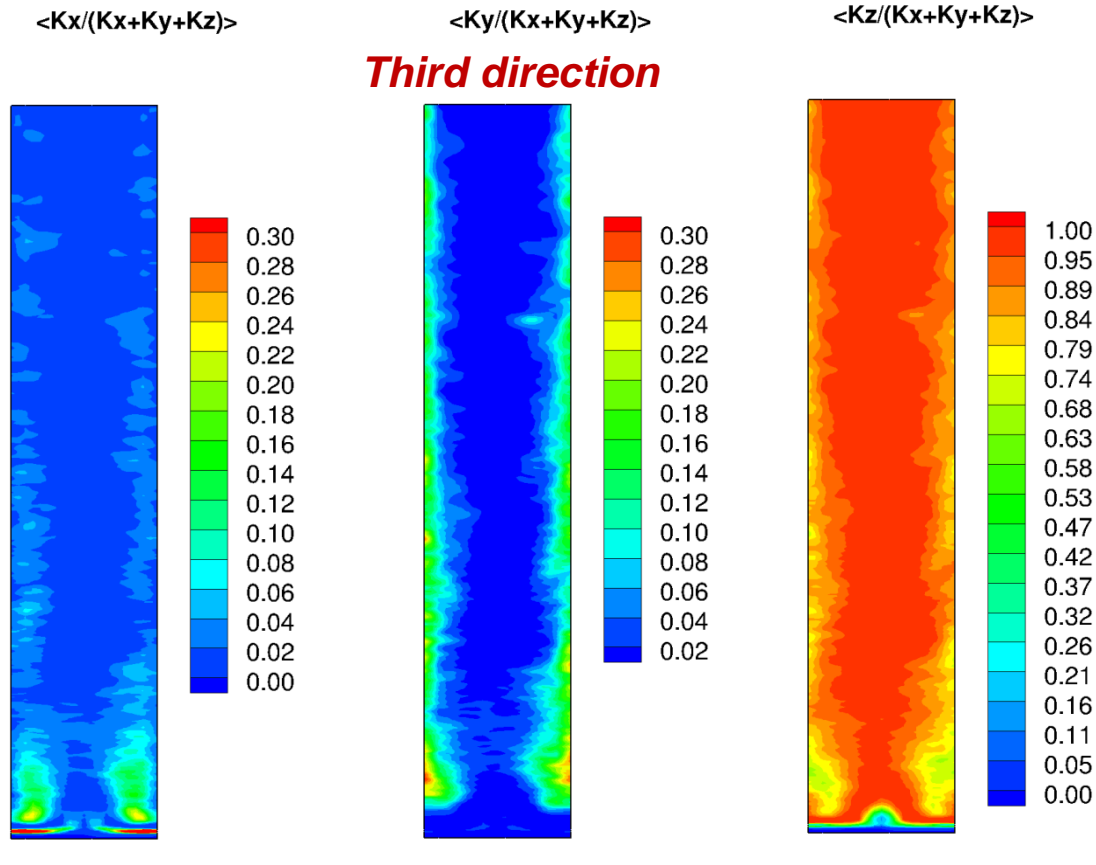
Radial profiles of mean (left) solids concentration (right) vertical solids velocity at the height of 2.1m

Similar solid holdups but quite different radial solids distributions and velocities



Discussion

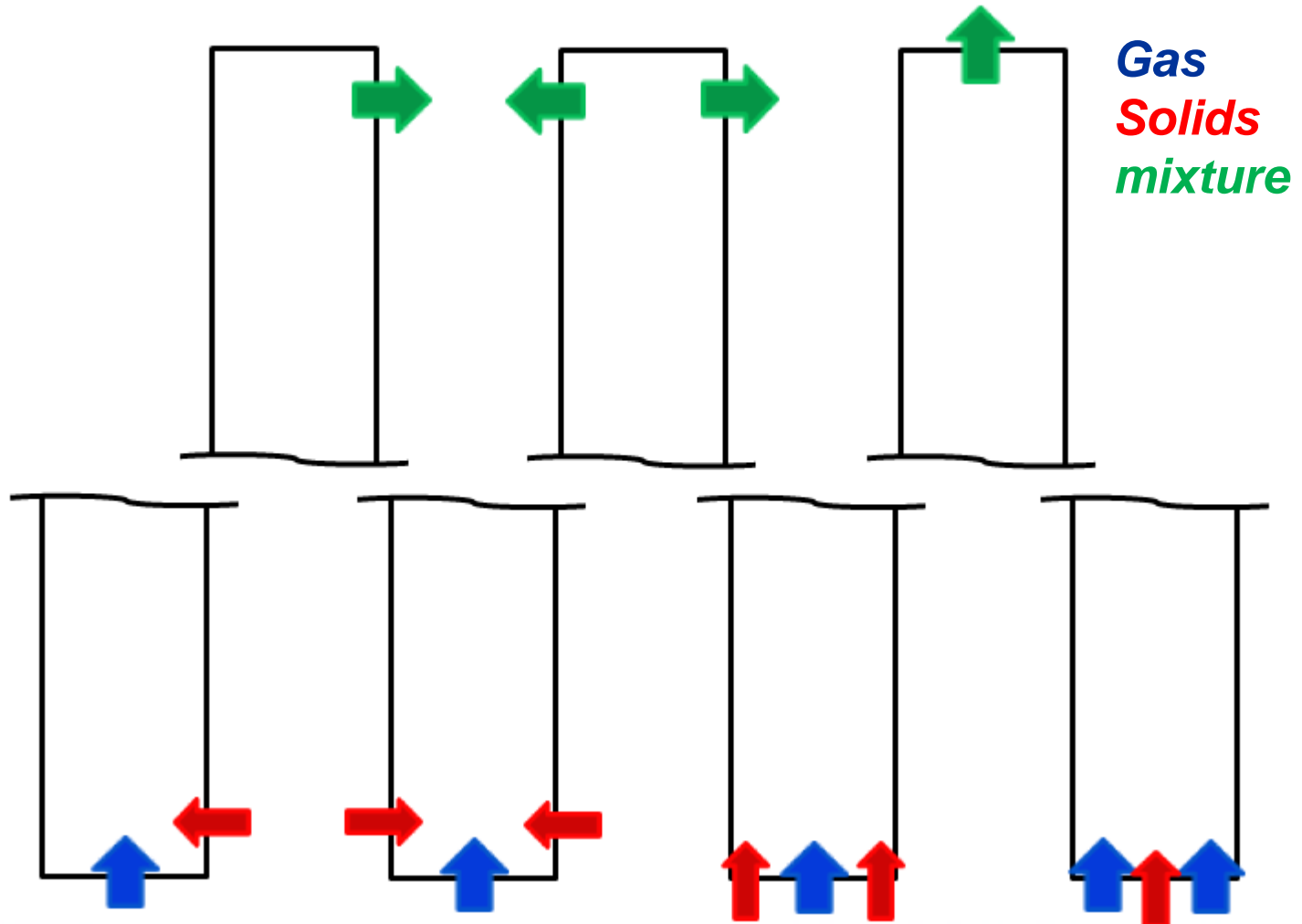
- Is movement in the third direction negligible?
 - No, especially close to wall; $K_x = 1/2 \rho v^2$; $K_y = 1/2 \rho w^2$; $K_z = 1/2 \rho w^2$



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

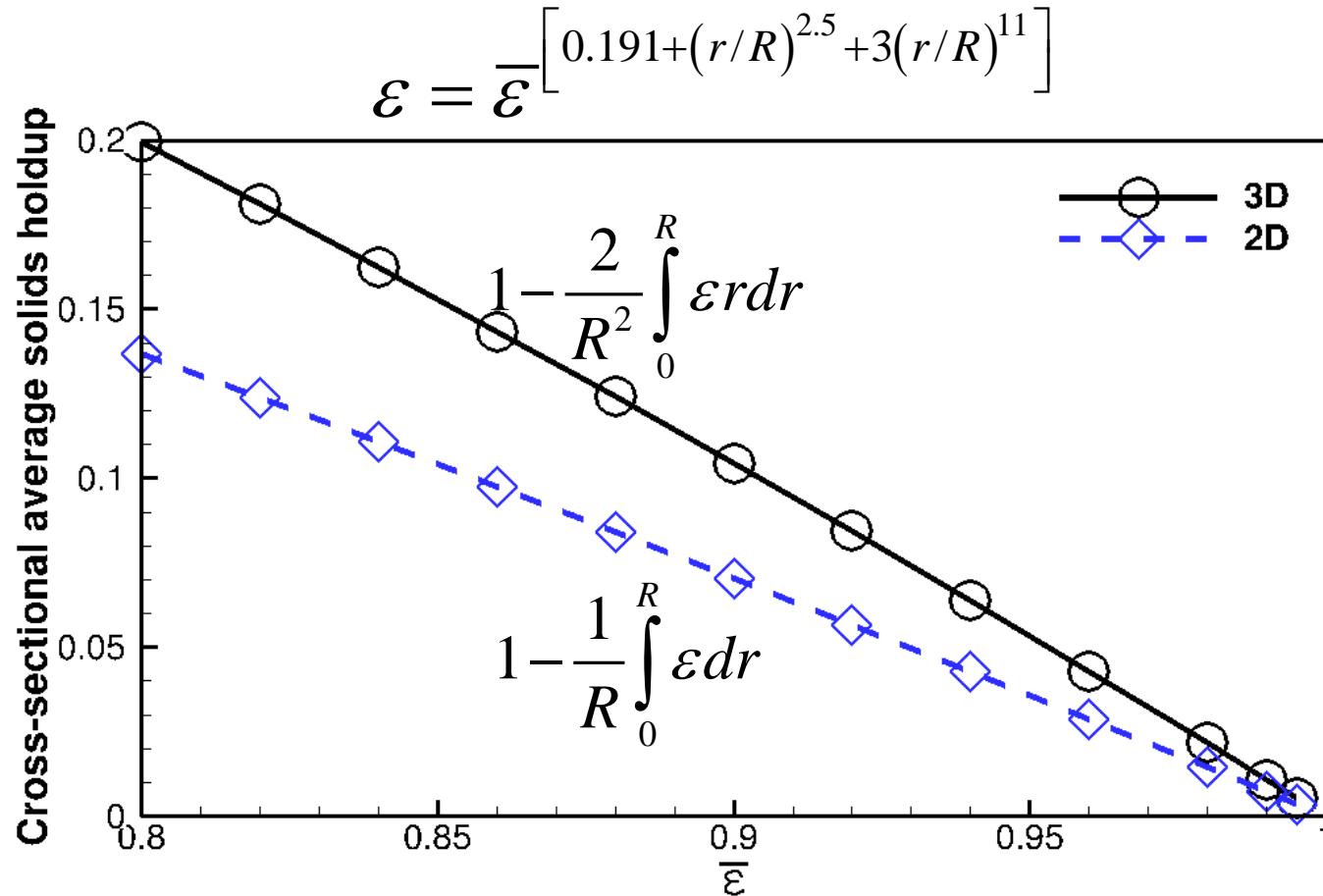
Discussion cont'd

- Hard to impose inlet and outlet boundaries in 2D



Discussion cont'd

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



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

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.**

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