CFD-DEM modeling the effect of column size & bed height on U_{mf} in micro fluidized beds with Geldart B particles

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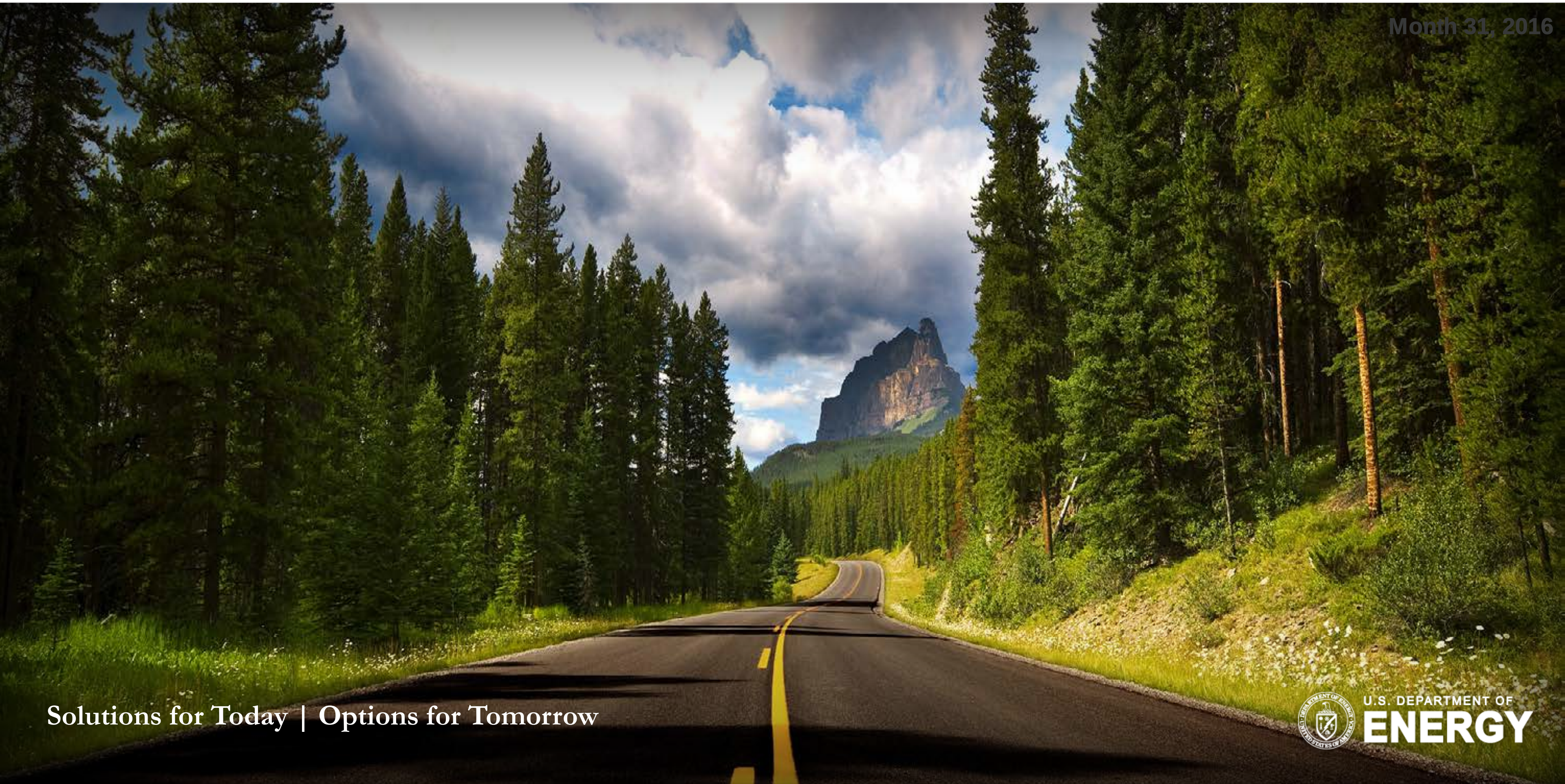
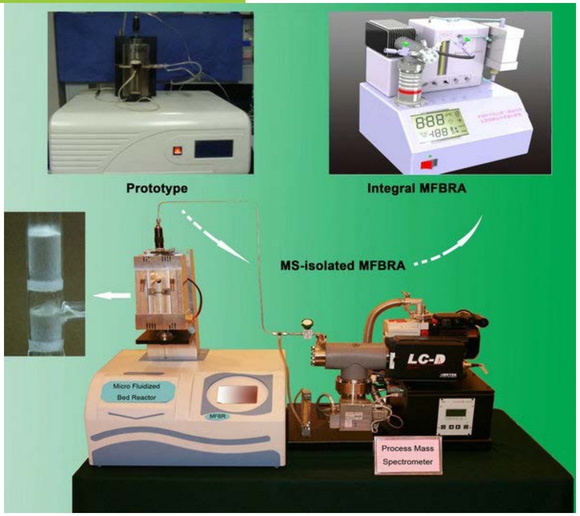


Outline

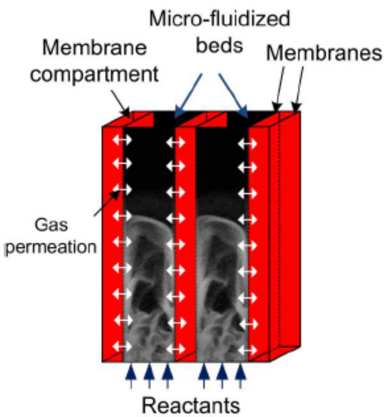
- Background and Motivation
- Simulation settings
- Results and discussion
- Conclusions

Motivation

- ❖ **Micro Fluidized Bed Reaction Analyzer (MFBRA)**
  - Integrate MFB with gas analysis spectrometer
  - Rapid heating and low diffusion
  - Online real-time isothermal differential reaction
  - Effective TGA-complementary instrument for gas-solid reactor analysis
  - Applications: pyrolysis, combustion, gasification, reduction, catalysis, and absorption.
- ❖ **Micro Membrane Fluidized Bed Reactor (MMFBR)**
  - Membrane bundle to add/remove gas
  - Optimal heat & mass transfer
  - Maximization of membrane area
  - Process integration and intensification



MFBRA @ CAS, China



MMFBR @ TUE, Netherlands

Fluidized bed membrane reactor

Pd-membrane assembly

Motivation

❖**Previous experimental studies**

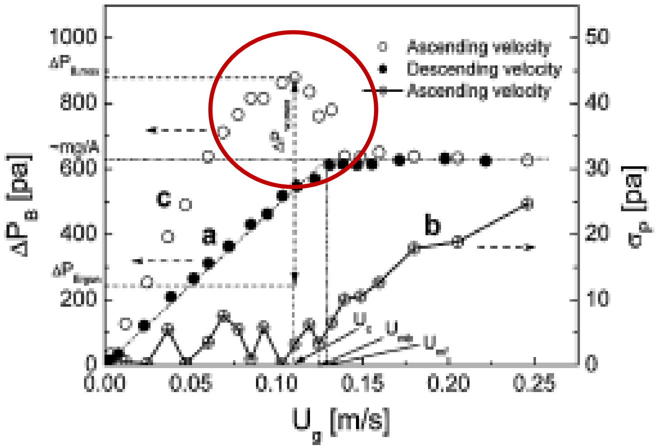
- ❖Column size range from mm to cm
- ❖Pressure overshoot exists in micro fluidized beds even for group B particles
- ❖U_{mf} is influenced by bed height and column diameter

❖**Wall effect dominates in micro-fluidized bed**

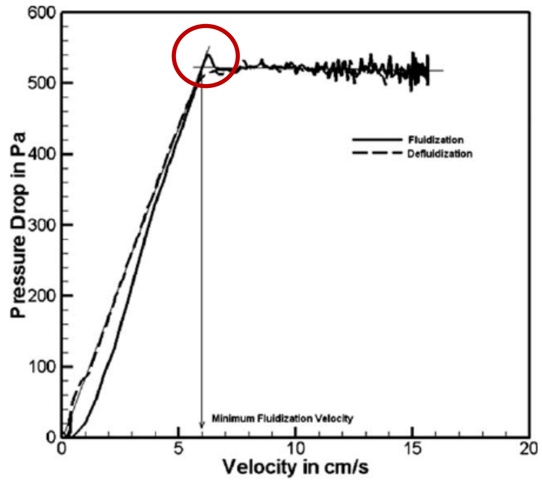
- ❖Di Felice and Gibilaro (2004) assume the wall effect is caused by the increase of bed voidage due to wall geometrical effect
- ❖Rao et al. (2010) consider the enhancing of particle-wall friction due to the increase of the ratio of wall area to bulk volume as the main reason

❖**To better understand the fluidization behavior in micro-fluidized bed reactors through CFD-DEM simulations**

- ❖Effect of column diameter and bed height on Umf
- ❖Detailed investigation on the wall effect



Liu et al. CEJ (2008)



Rao et al. AIChE (2010)

Simulation approach

Multiphase Flow with Interphase eXchanges - Discrete Element Model (**MFIX-DEM**)

- Cartesian grids are used to discretize the computational domain.
- Boundary cells are truncated to conform the domain surface (Cut-cell meshing technique).
- Hybrid parallel mode with distributed memory parallel (DMP) and shared memory parallel (SMP) using message passing interface (MPI) and open multi-processing (OpenMP).

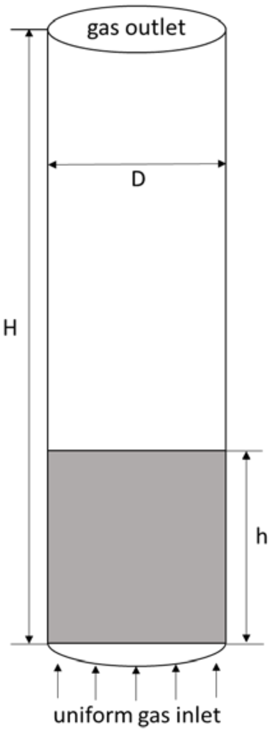


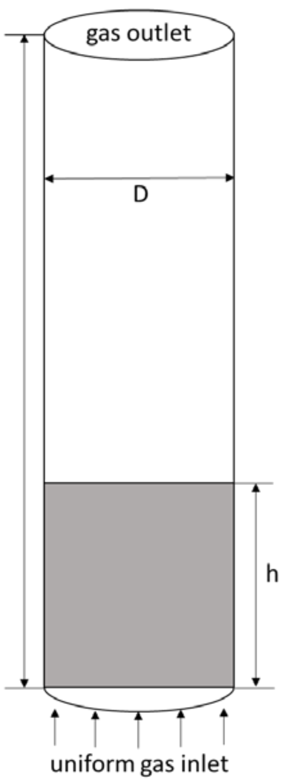
Table 1: Parameters used in the numerical simulations

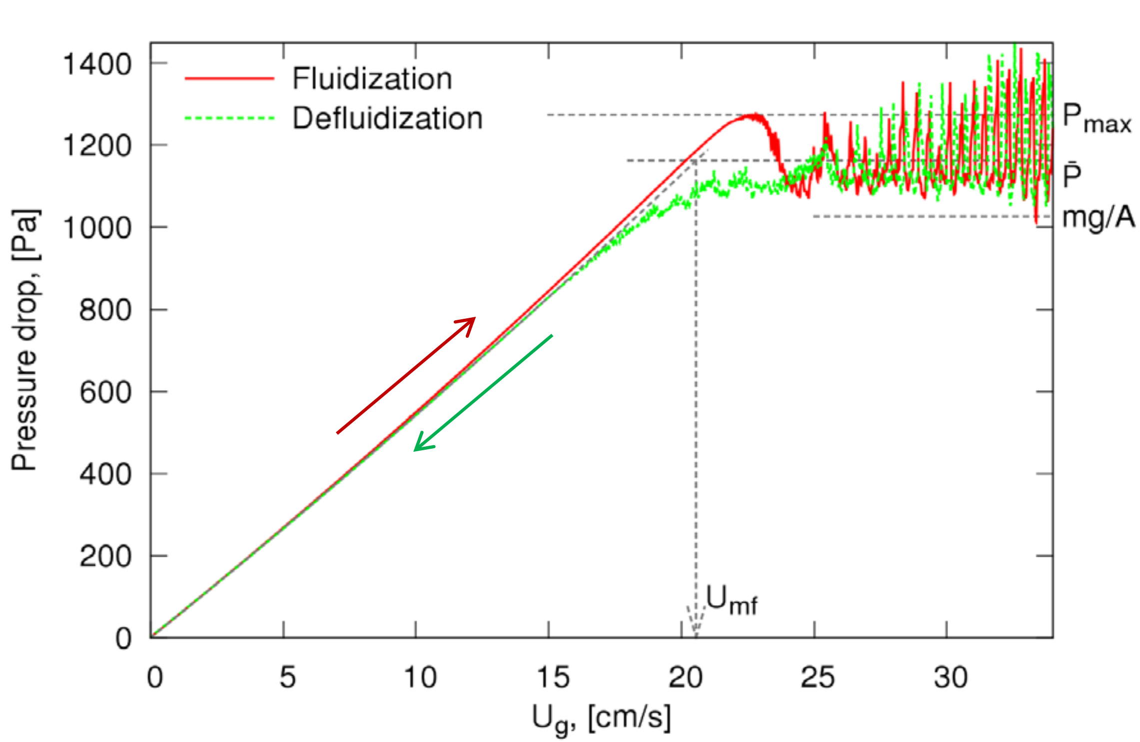
Parameter	Unit	Value
Gravity y-direction	m/s2	9.81
Gas density	Kg/m3	1.2
Gas viscosity	Pa·s	1.8e-5
Particle diameter	µm	550
Particle density	kg/m3	2500
Particle sphericity	-	0.9
Restitution coefficient (normal)	-	0.99
Restitution coefficient (tangential)	-	0.3
Friction coefficient between particles	-	0.4
Friction coefficient between particle and wall	-	0.4
Normal spring stiffness	N/s	100

Results

An example (D=0.80 cm & h = 6.88 cm)

- The air velocity was slowly increased beyond the point of fluidization and then decreased to zero to get the entire pressure drop profile (gas velocity increase/decrease rate: 1 cm/s)
- Both the pressure overshoot and increasing of U_{mf} were captured by our simulations



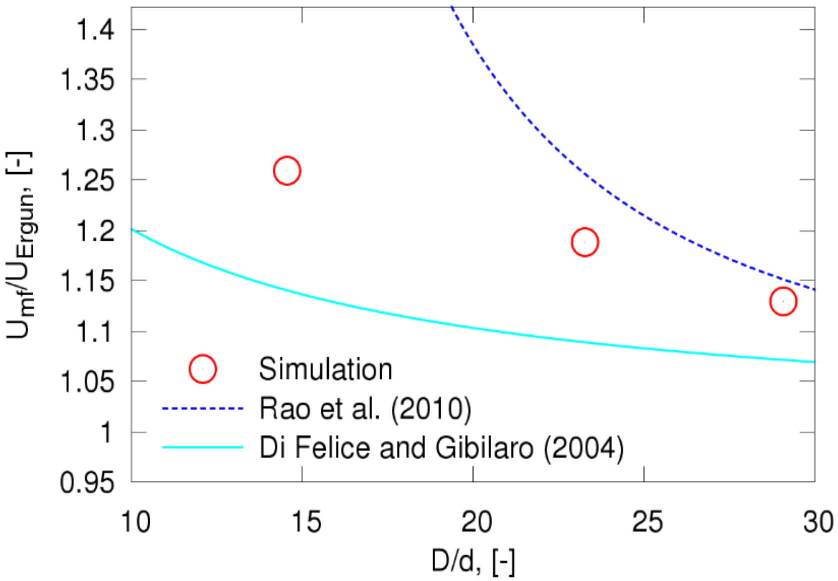


$$\Delta P = \overline{P} - \frac{mg}{A}$$

$$\Delta P_{\max} = P_{\max} - \frac{mg}{A}$$

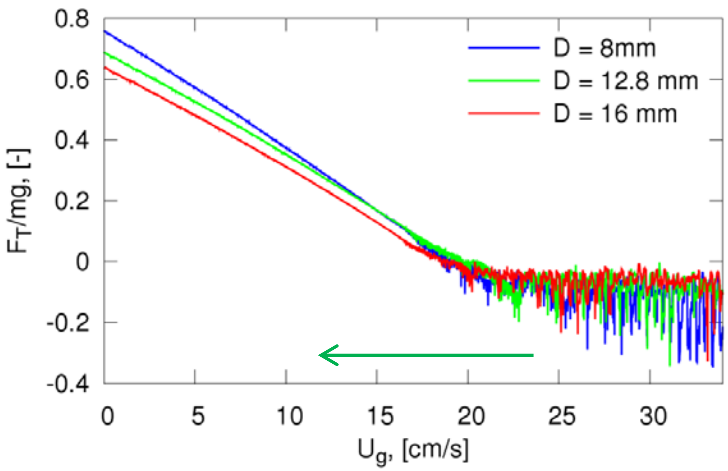
Results

Effect of different column diameters (D=0.80 cm, 1.28 cm, 1.60 cm & h = 6.88 cm)



Packing densities under different column diameters

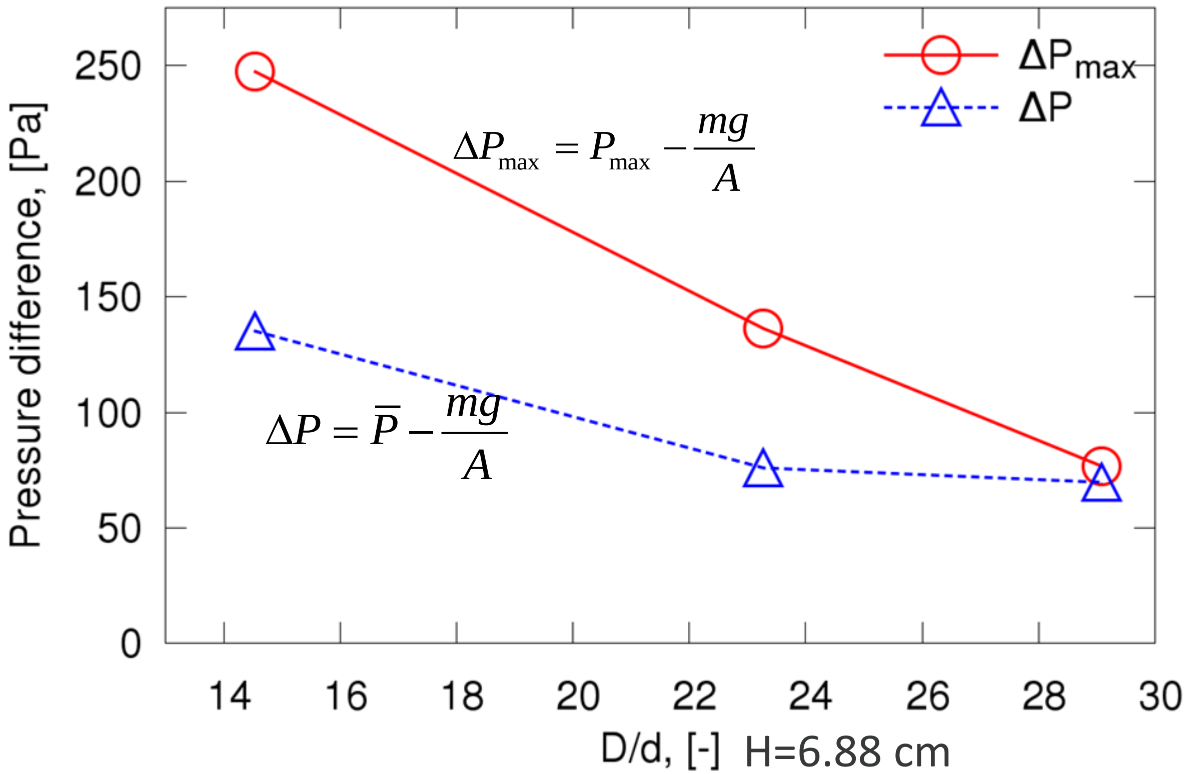
	0.8 cm	1.28 cm	1.60 cm
ε_s	0.6143	0.6204	0.6240



- The packing density increases with increasing column diameters, which contributes to the decrease of minimum fluidization velocity.
- The fraction of bed weight supported by the wall decreases with increasing column diameter during defluidization stage.
- These two factors, frictional and geometrical effects from the wall, are coupled and hard to distinguish.

Results

Pressure differences for different column sizes

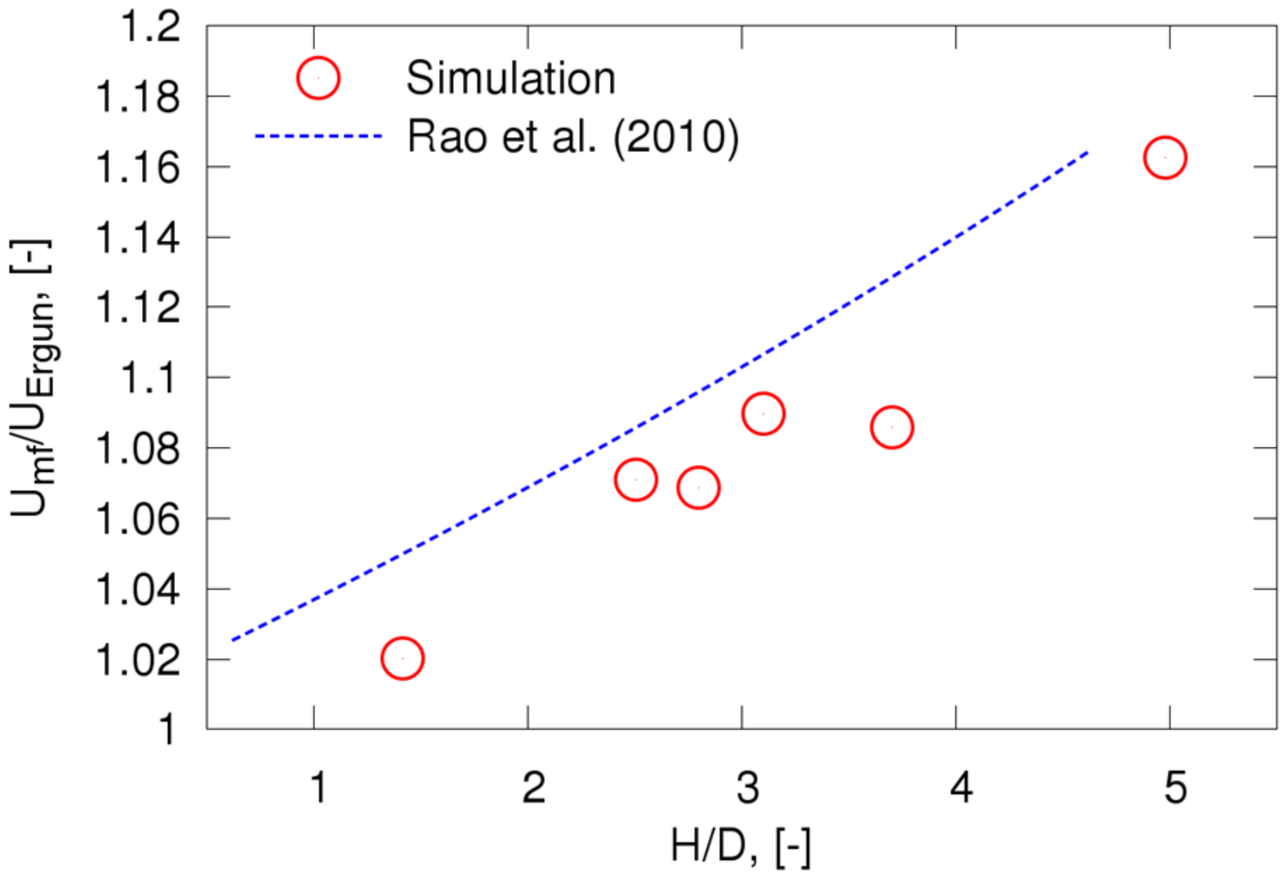


H=6.88 cm

- The pressure differences for a fixed bed height with varying column diameters both decrease with increasing column diameter.
- The difference ($\Delta P_{max} - \Delta P$) characterizing pressure overshoot decreases with increasing column diameters.

Results

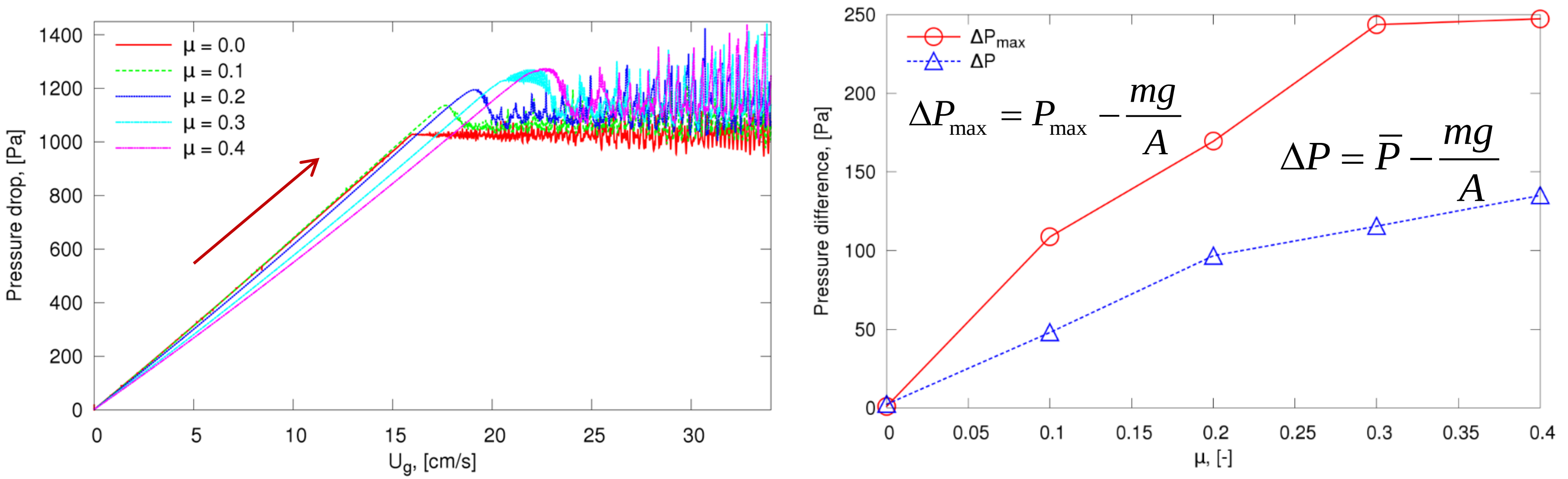
Effect of static bed height (D = 1.6 cm)



- Umf increases with static bed height which highlights the frictional effect
- Results agree well with experimental observation and Rao's correlation.

Results

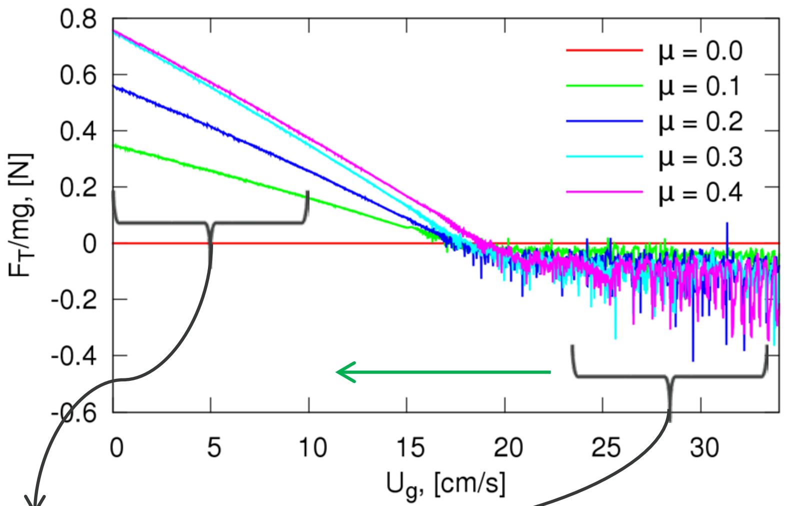
Parametric study of wall friction (D=0.8 cm; H=6.88 cm)

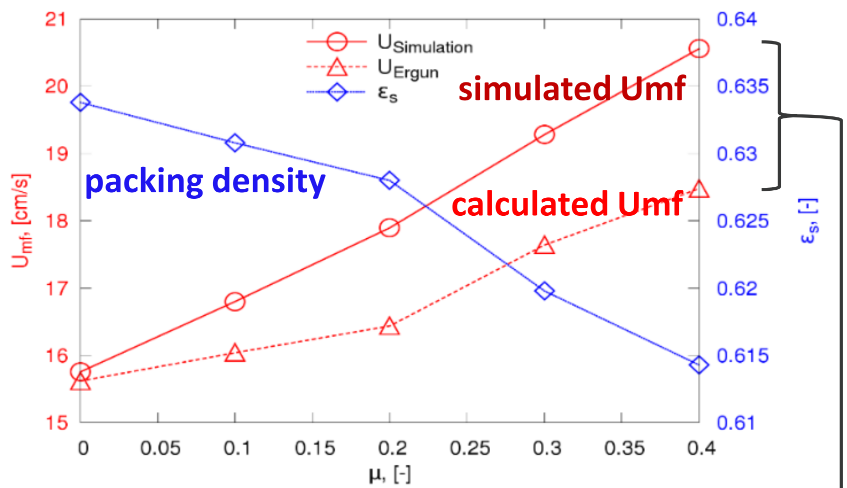


- The frictional effect is investigated by varying the particle-wall friction coefficient μ from 0.0 to 0.4 for the 0.8 cm bed diameter and 6.88 cm static bed height.
- When particle-wall friction is 0, there is no noticeable pressure overshoot. As the particle-wall friction coefficient increases, both the overshoot and average bed pressure drop increase.
- Pressure differences increases with particle-wall friction suggesting stronger frictional force.

Results

Parametric study of wall friction (D=0.8 cm; H=6.88 cm)

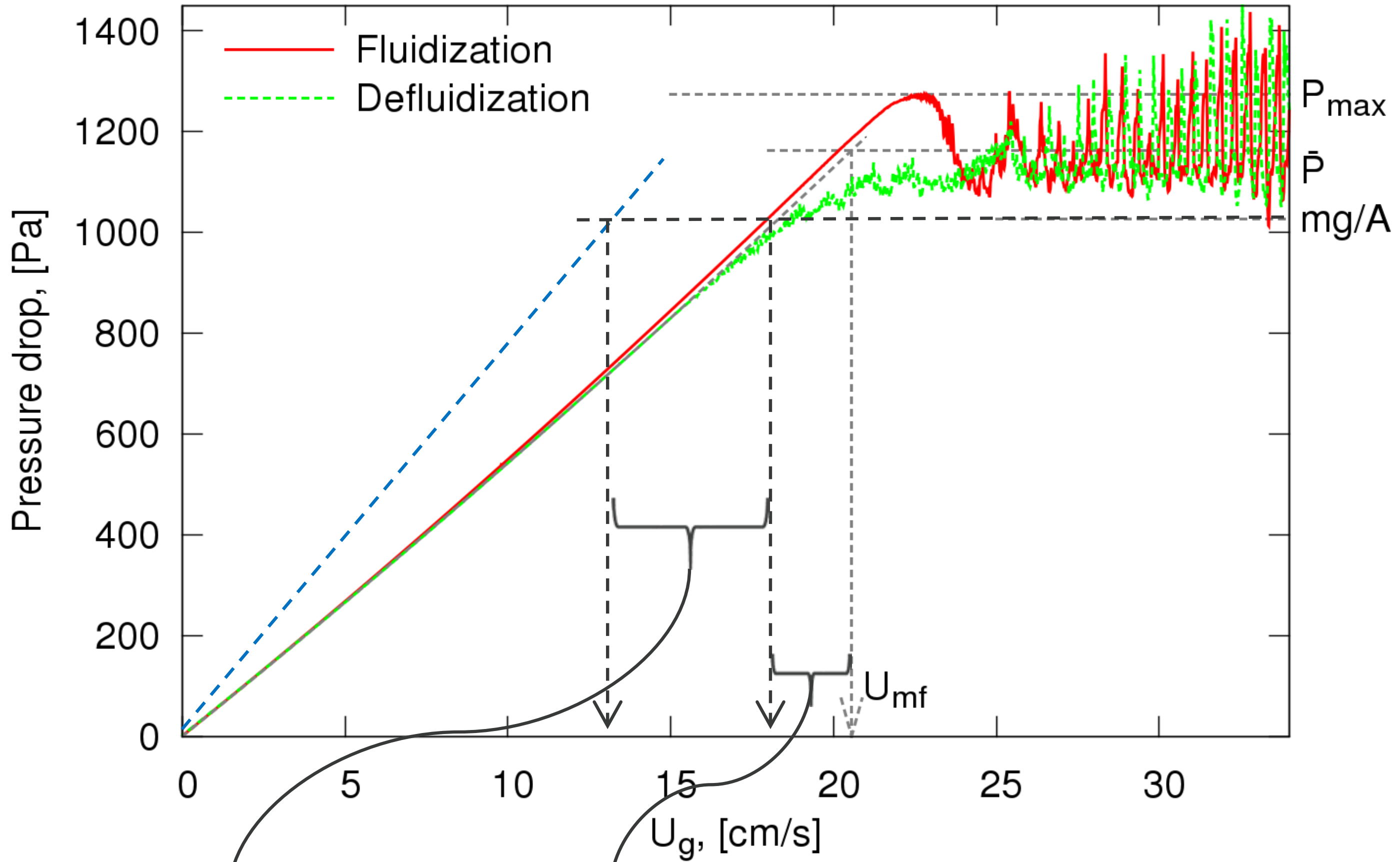




- The positive tangential force during defluidization indicating the wall partially supports the weight of particles.
- The negative particle-wall tangential force during fluidization indicates upward particle movement.
- The packing density decreases from 0.634 to 0.614 when particle-wall friction coefficient is increased from 0 to 0.4. The increased porosity leads to less flow resistance, hence delays in Umf.
- The elevated pressure drop due to wall friction further delays the onset of fluidization.

Results

Wall effect on Umf



- Wall effect: **particle packing** and **wall friction** both delay Umf for micro-fluidized bed in this study

Conclusions

- The effect of column diameter and bed height on Umf was investigated for micro-fluidized beds of group B particles using MFIX-DEM.
- Decreasing column diameter and increasing bed height led to high Umf due to the stronger wall effect which is consistent with experimental results.
- Detailed analysis on wall effect was conducted including the wall geometrical effect and particle-wall friction.
- CFD-DEM is a very powerful tool to investigate fluidization characteristics of micro-fluidized beds.

Acknowledgements & Disclaimer

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