Eulerian simulation of an 8” circular fluidized bed unit at PSRI using EMMS drag model in Simcenter STAR-CCM+

Behzadi, A., Tandon, M., Eppinger, T.
Siemens Digital Industries Software

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Outline

- Motivation
- EMMS Drag Model
- Fluidized Bed Regimes
- PSRI 8" CFB Unit
- Results
- Conclusion

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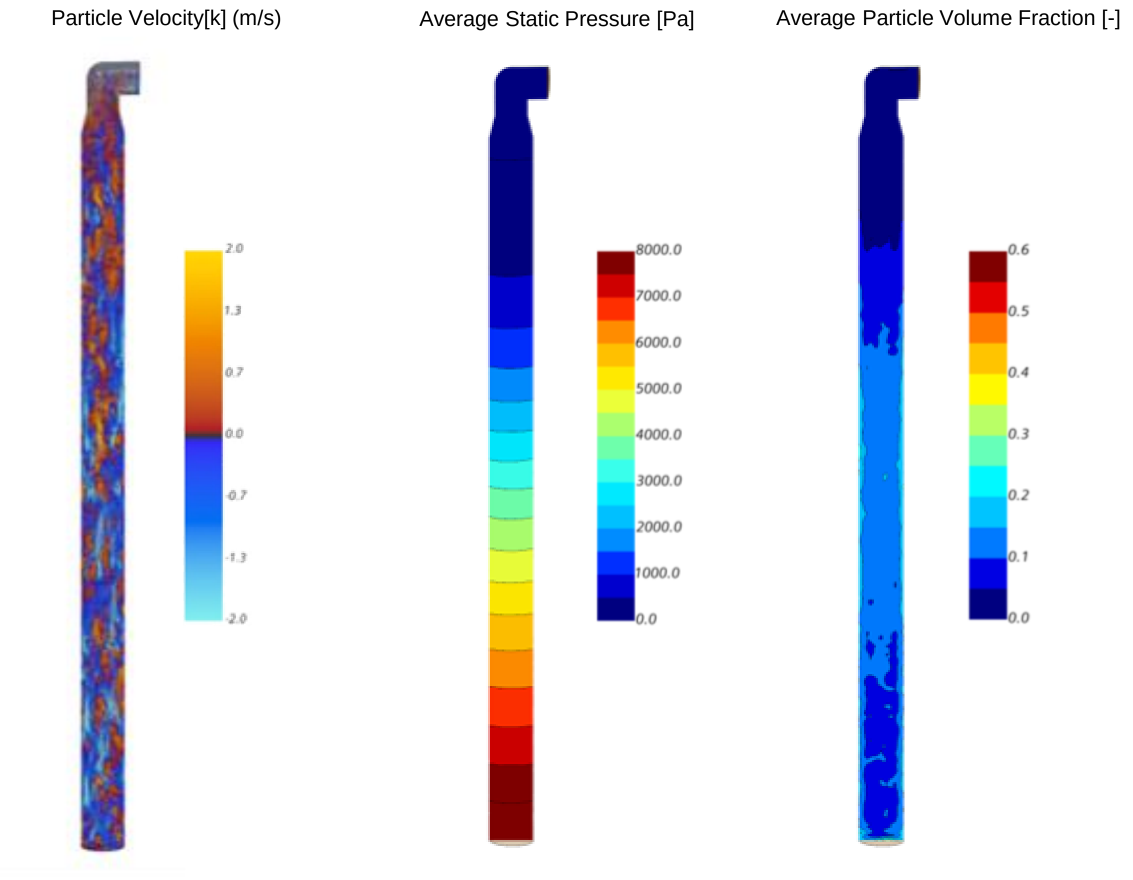
Motivation

Capturing heterogeneity in fluidized bed related flows

Meso-scale structures in gas-solid flow simulations

Alternatives to the traditional homogeneous drag models

Energy Minimization Multi-Scale (EMMS) - minimization of energy interchanged between the coexisting gas and solid phases



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EMMS Drag Model

- Drag exerted on a heterogeneous suspension of particles
- Significant drag modification due to sub-grid heterogeneous structures
- Classic EMMS model was proposed by Li and Kwauk (1994)
- Mesoscale flow structure was decomposed into the dense and dilute phases
- Optimizing a stability condition under the constraint of a set of mass and force balance equations
- Extending the EMMS model to the sub-grid level leads to various EMMS-based drag models
- Regime-dependent scenarios of the mesoscale flow structure, e.g., bubbles or clusters
- Wang and Li, 2007; Lu et al., 2009; Lu et al., 2011 Luo et al., 2017; Tian et al., 2020

EMMS Drag Model

For a heterogeneous fluidized bed, the EMMS gas–solid drag coefficient is defined by

$$\beta = \frac{3}{4} C_{D0} \frac{\varepsilon_s \varepsilon_g \rho_g |v_s - v_g|}{d_p} \varepsilon_g^{-2.65} H_D$$

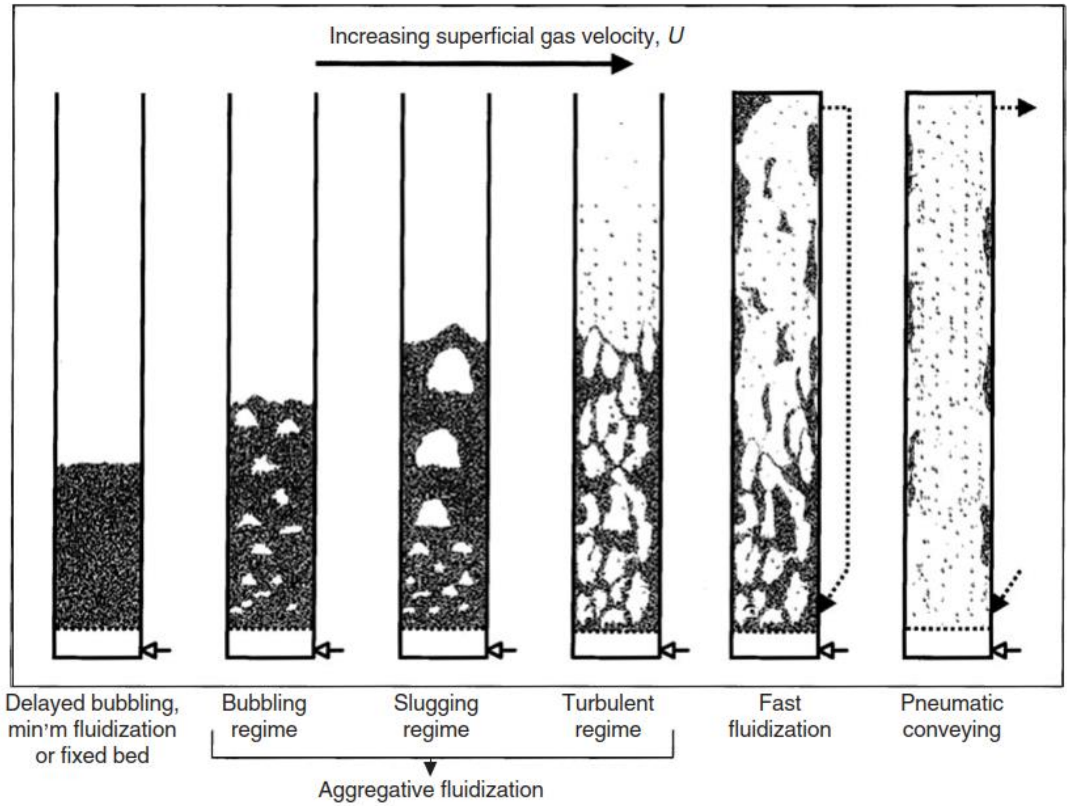
$H_D = f(\varepsilon_S)$: Heterogeneity index (Wang and Li, 2007)

H_D is a measure of discrepancy between the homogeneous drag (e.g., the drag coefficient of Wen and Yu, 1966) and the EMMS drag

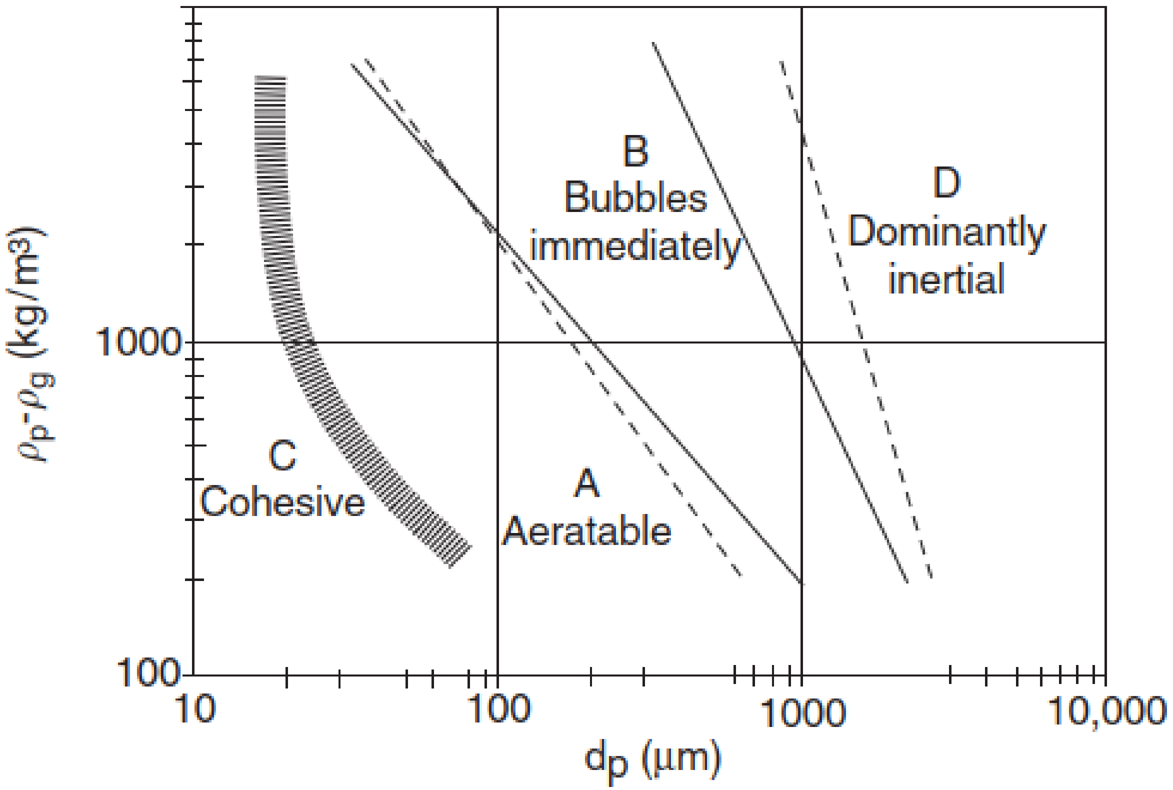
The drag coefficient for an individual particle is expressed as

$$C_{D0} = \begin{cases} \frac{24}{Re}(1 + 0.15\mathrm{Re}^{0.687}), & Re < 1000 \\ 0.44, & Re \geq 1000 \end{cases}$$

Fluidized Bed Regimes



Flow regimes relevant to gas-solid fluidization, Grace J.R. etal, 2006



Geldart powder groups for fluidization by air at room temperature and atmospheric pressure, Geldart 1973

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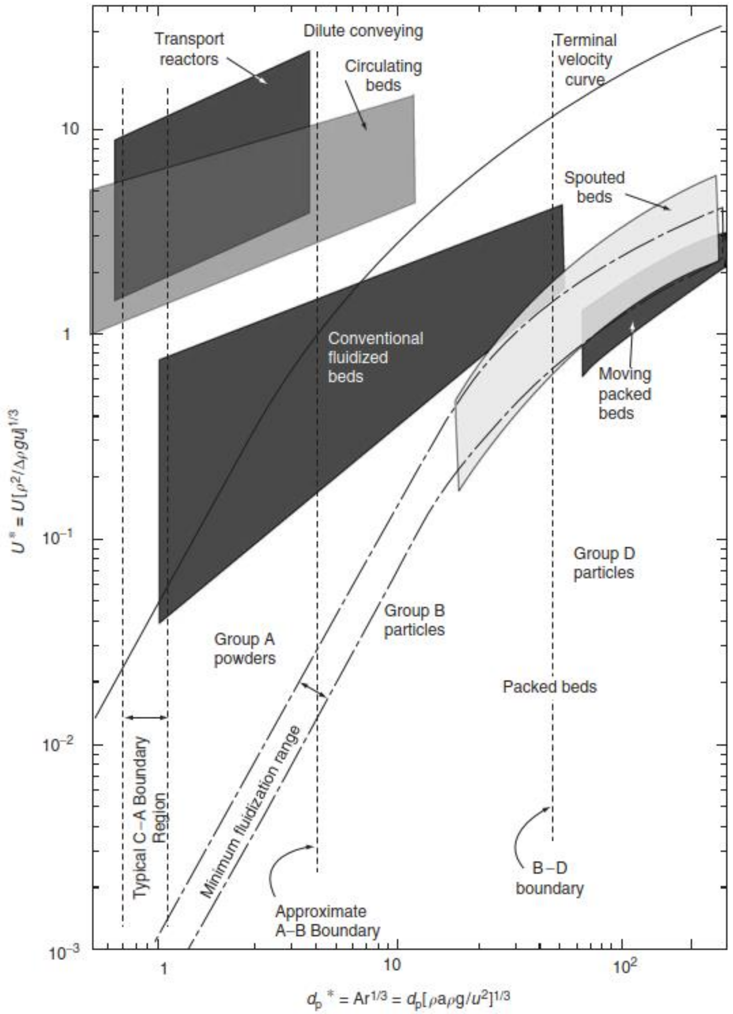
Fluidized Bed Regimes



Dimensionless flow regime map for upward gas flow through solid particle diagram, Grace J.R., Can J., Chem Eng., 64, 353, 1986a

- Onset of turbulent fluidized bed

Grace et al., 2006

$$Re_c = \frac{\rho_g d_p U_c}{\mu_g} = B\,Ar^{\eta}$$

$$B = 0.565 \qquad \eta = 0.461$$

- Onset of fast fluidization

Bi et al., 1995

$$Re_{sc} = 1.53 Ar^{0.5} \quad \text{or} \quad U_{sc} = 1.53\sqrt{\frac{g(\rho_p - \rho_g)d_p}{\rho_g}}$$

Where

$$Ar = \frac{g\rho_g(\rho_p - \rho_g)d_p^{\ 3}}{\mu_g^{\ 2}}$$

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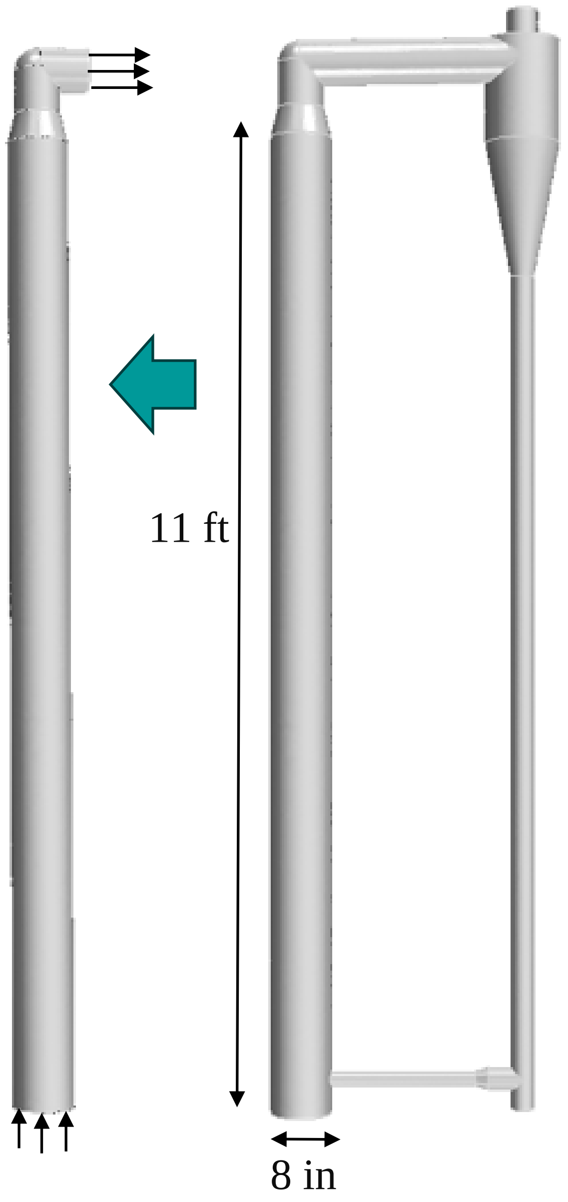
PSRI – 8" Circulating Fluidized Bed Unit

- Particle Sauter diameter: 36.24 μm
- Particle density: 2500 kg/m3

- Initial bed height: ~2ft
- Gas density: 1.184 kg/m3
- Gas viscosity: 1.855×10-5 kg/m s

- Maximum packing limit, 0.624
- Superficial velocity: 0.229 m/s,
  0.318 m/s, 0.615 m/s
  (no entrainment in experiment)



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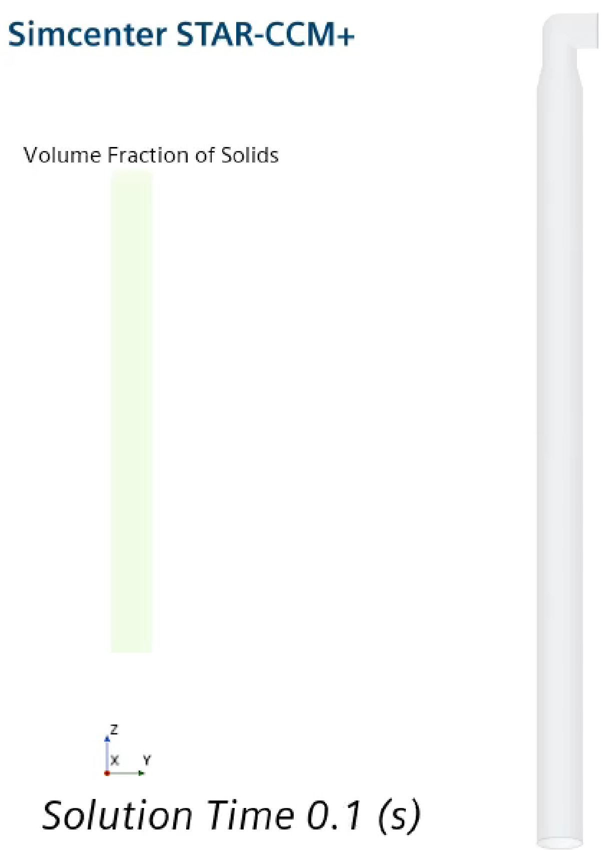
PSRI – 8" Circulating Fluidized Bed Unit

- STAR-CCM+ Eulerian-Eulerian modelling –
  Kinetic Theory of Granular Flow (KTGF)
- Granular Pressure
- Granular Temperature
- Gidaspow Drag Model / EMMS drag correlation (Turbulent / Fast Fluidization)
- Modified Johnson frictional model
- Gidaspow viscosity and granular diffusion model
- Radial distribution function by Ding-Gidaspow
- Pressure Gradient Force
- Phase-coupled segregated Solver

PSRI – 8" Circulating Fluidized Bed Unit

- No-slip gas-wall boundary
- Slip for solid-wall boundary
- Time step: 1e-4 s
- Max iterations/ Time step = 20
- Restitution coefficient = 0.9
- Simulation time: 25 s (results averaged over 20 s)
- 160 processors on Intel(R) Xeon(R) Gold 6248 CPU @ 2.50GHz

Results
Volume Fraction



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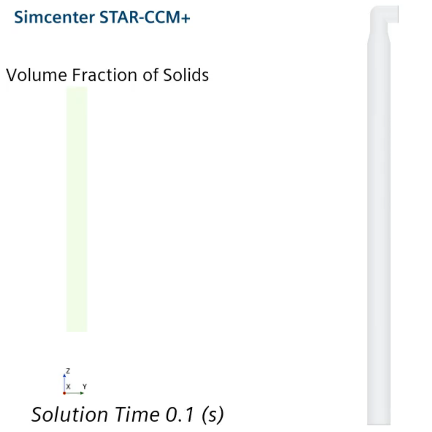
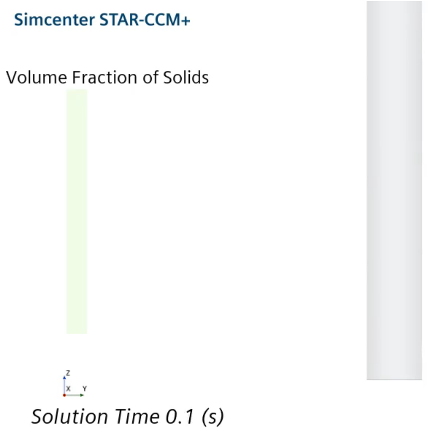
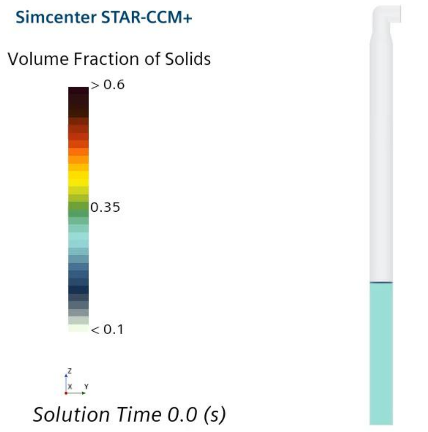
Comparison Fast vs Turb, v_in = 0.229 m/s
Volume Fraction

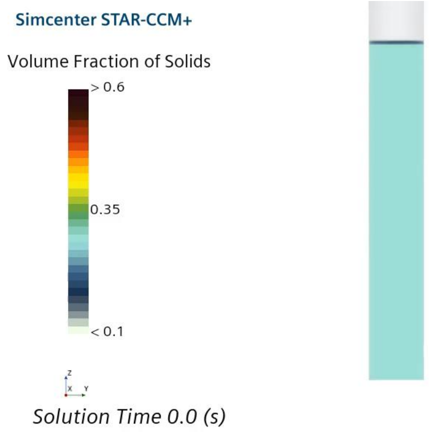
Fast





Turbulent





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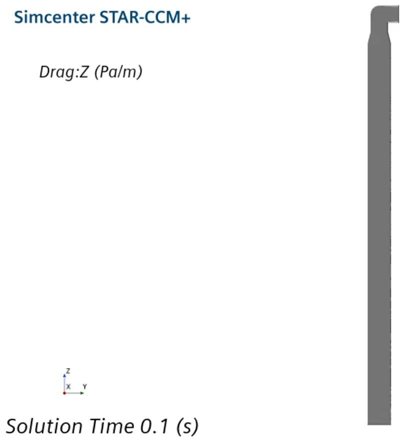
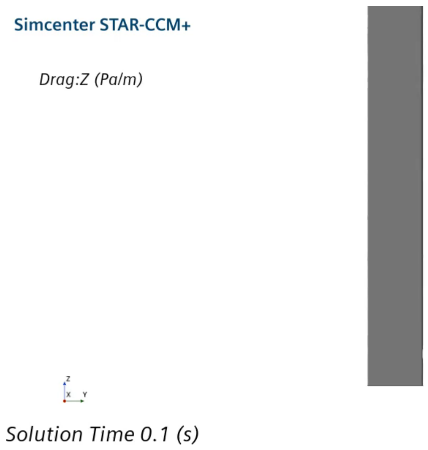
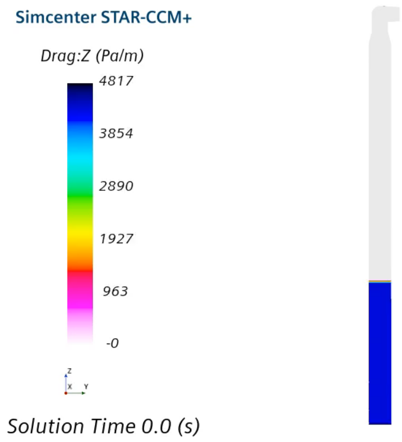
Comparison Fast vs Turb, v_in = 0.229 m/s
Eulerian Drag Z-direction

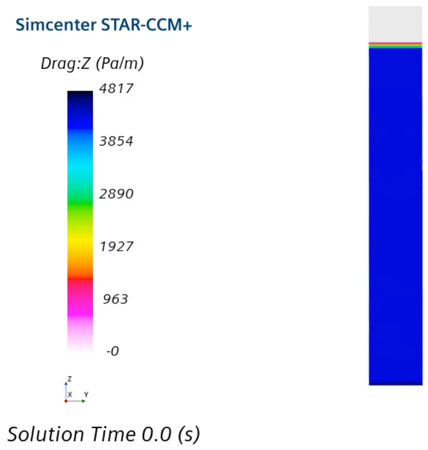
Fast





Turbulent





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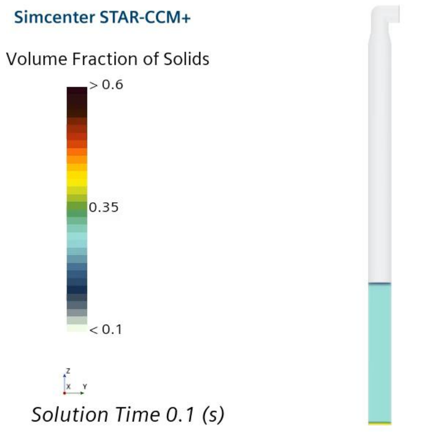
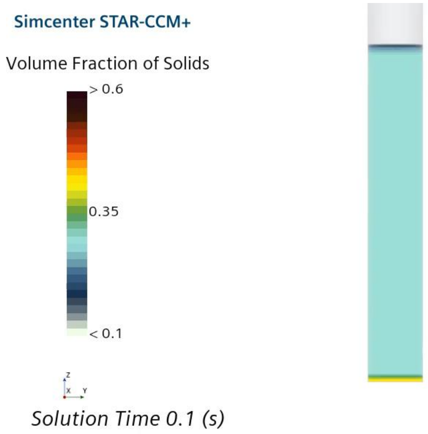
Comparison Fast vs Turb, v_in = 0.318 m/s
Volume Fraction

Fast





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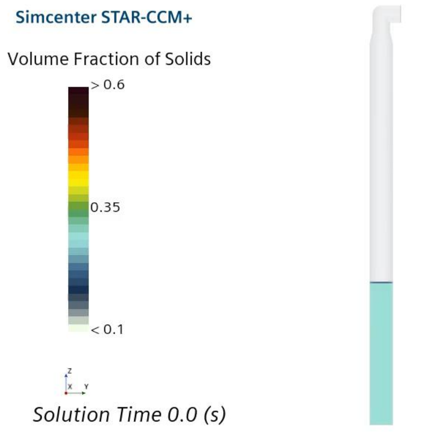

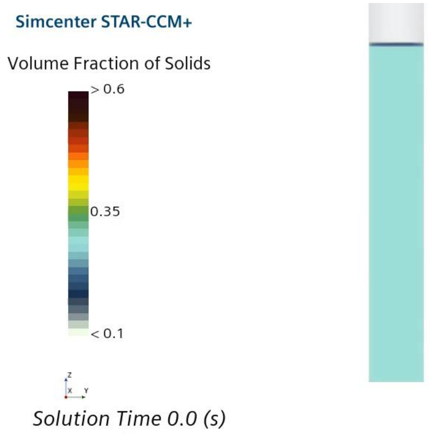

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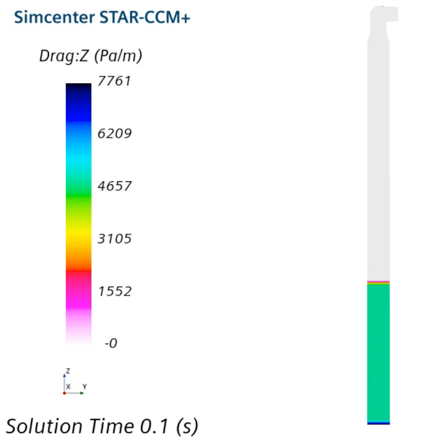
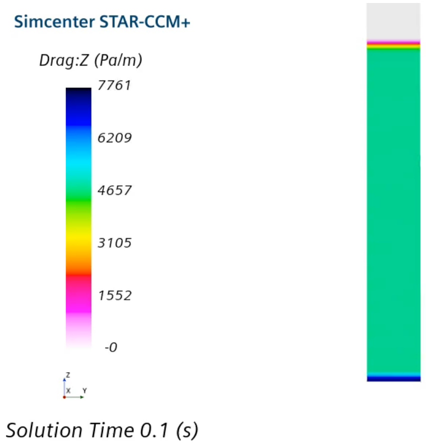
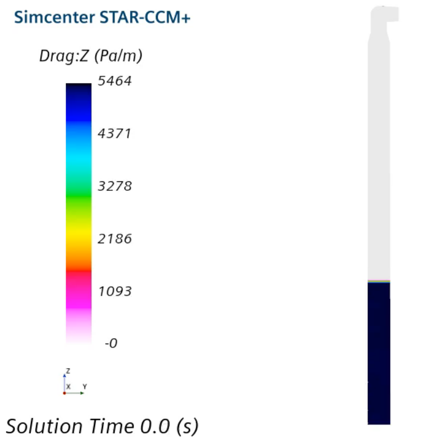
Comparison Fast vs Turb, v_in = 0.318 m/s
Eulerian Drag Z-direction

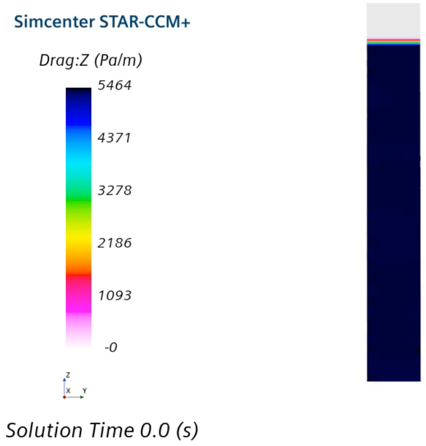
Fast





Turbulent





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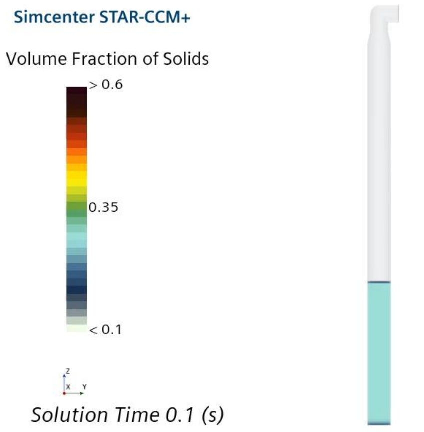
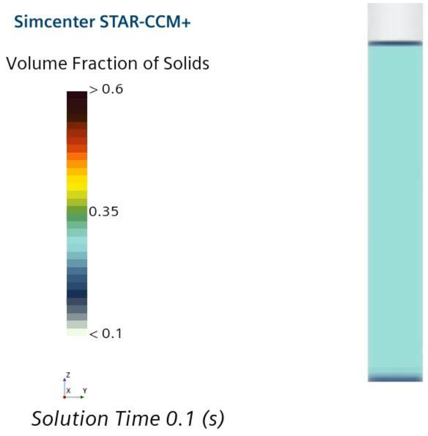
Comparison Fast vs Turb, v_in = 0.615 m/s
Volume Fraction

Fast





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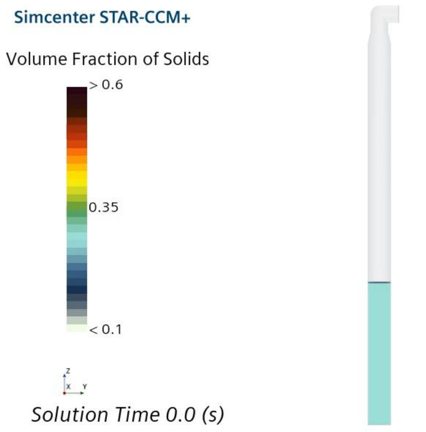

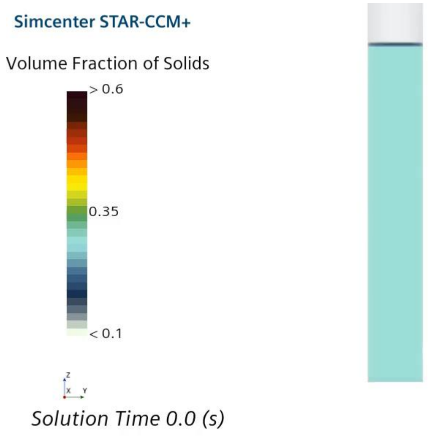

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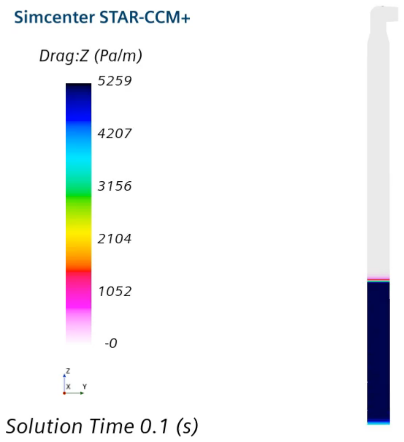
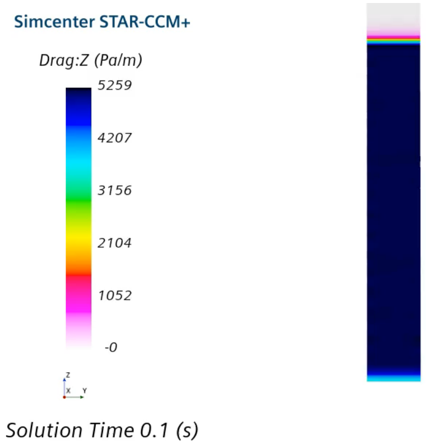
Comparison Fast vs Turb, v_in = 0.615 m/s
Eulerian Drag Z-direction

Fast





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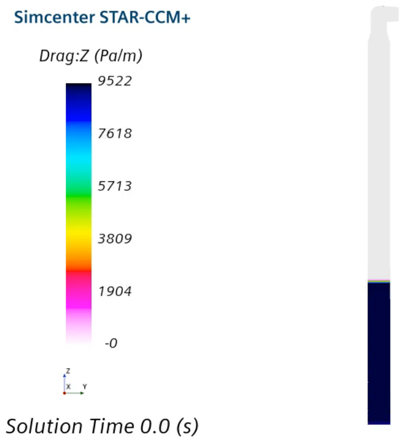

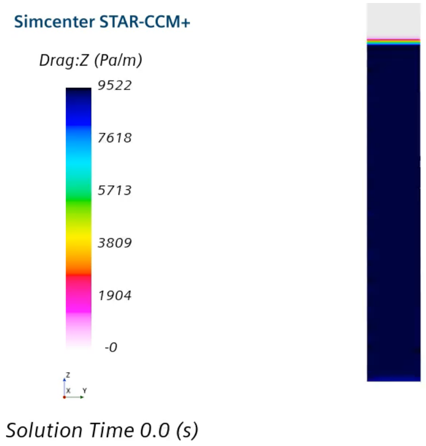

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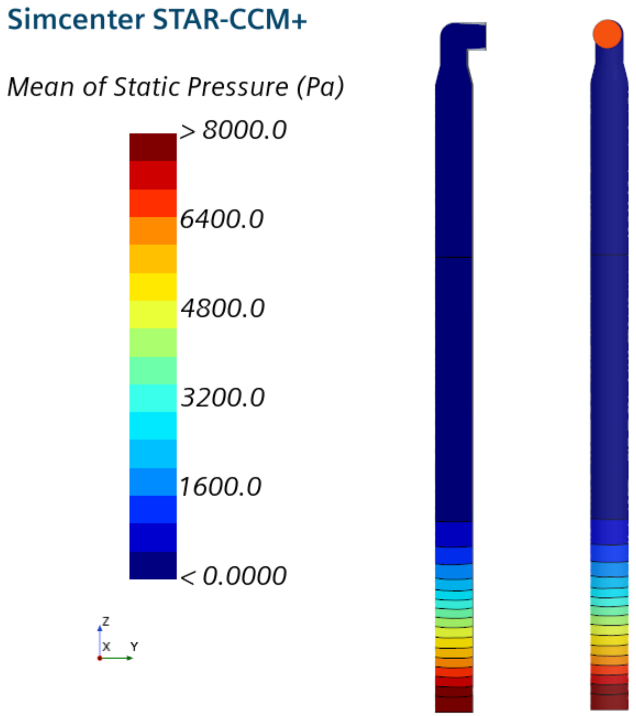
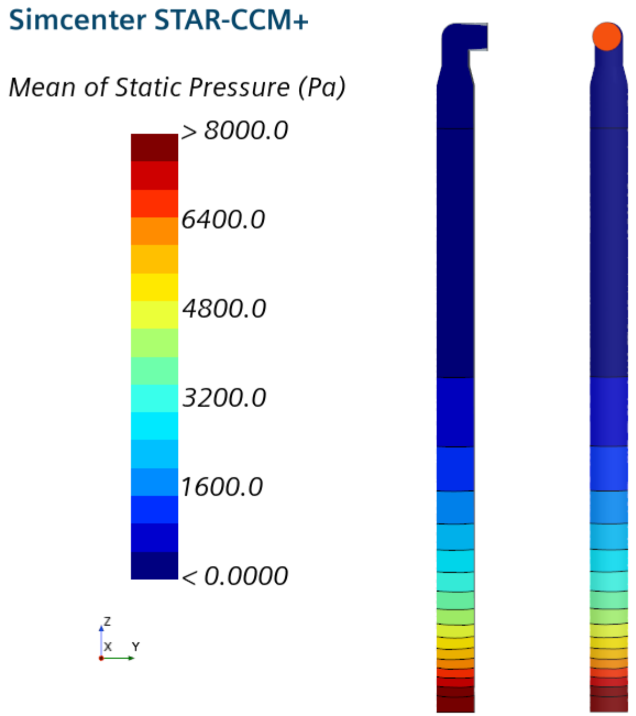
Pressure distribution
Turbulent fluidization

v_{in} = 0.229 m/s



v_{in} = 0.318 m/s



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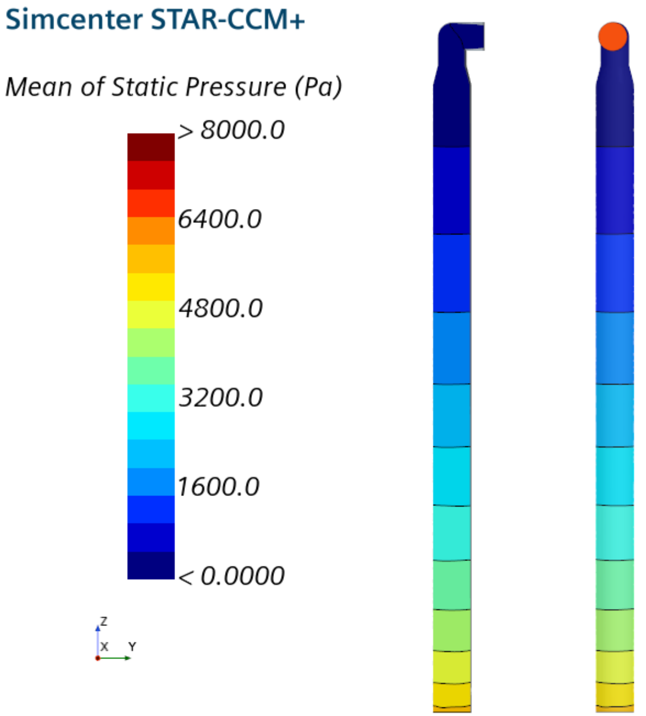

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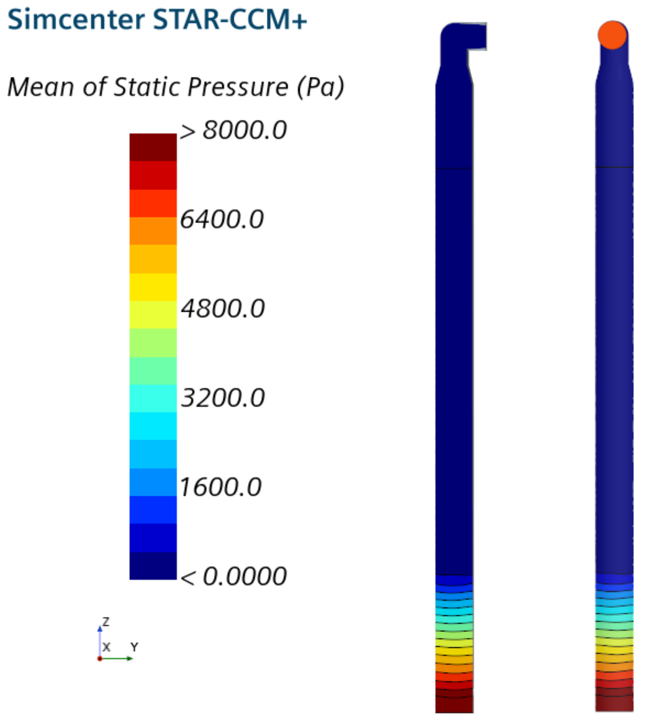
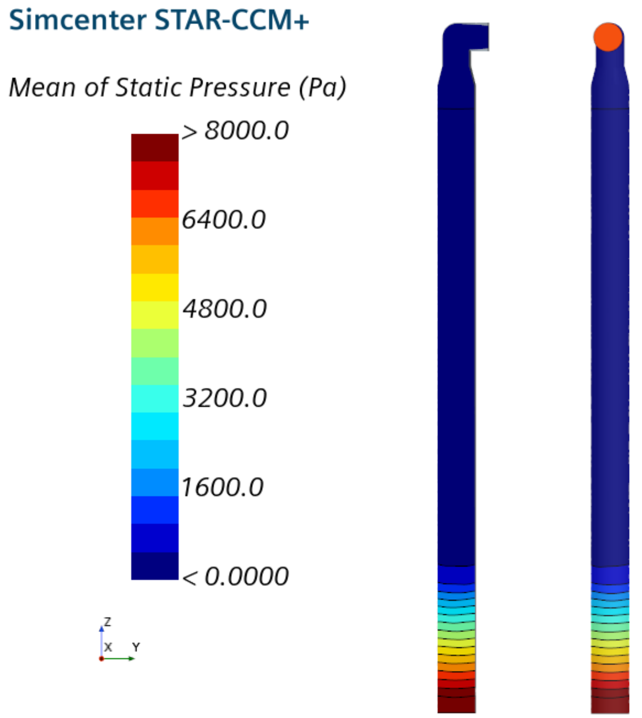
Pressure distribution
Fast fluidization

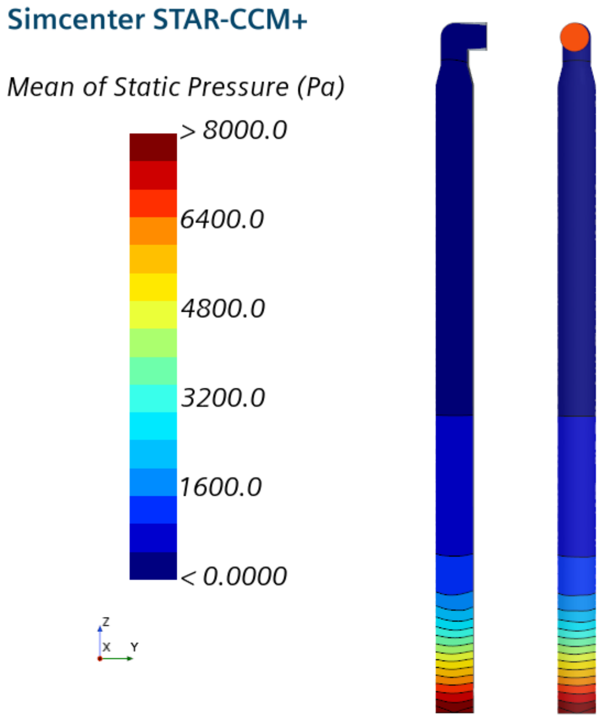
v_{in} = 0.229 m/s



v_{in} = 0.318 m/s



v_{in} = 0.615 m/s



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Pressure distribution

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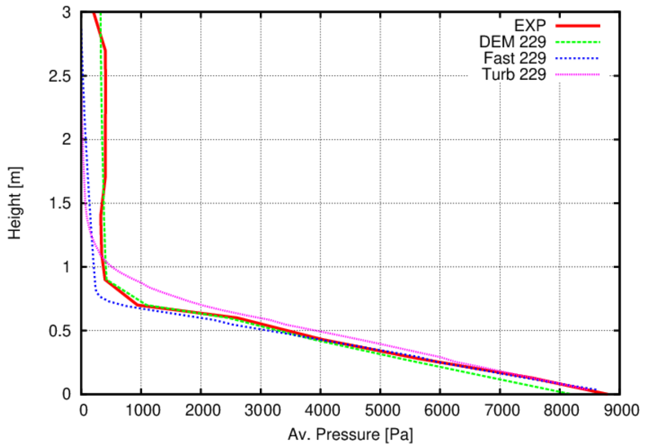

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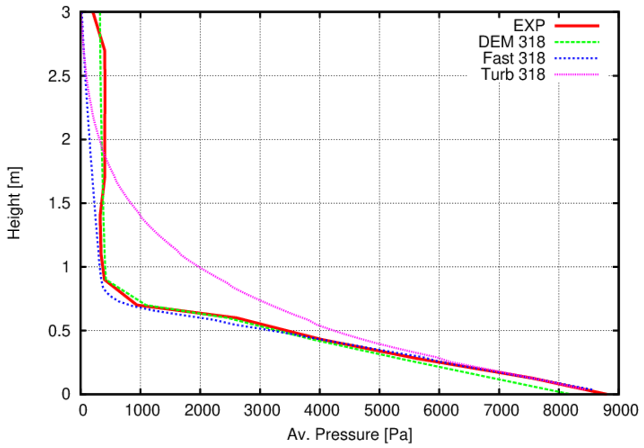

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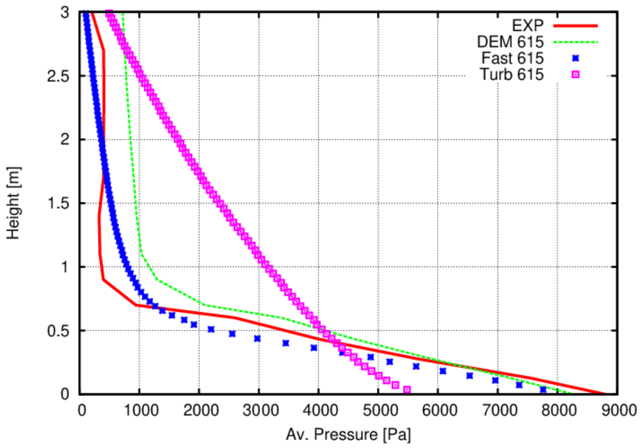

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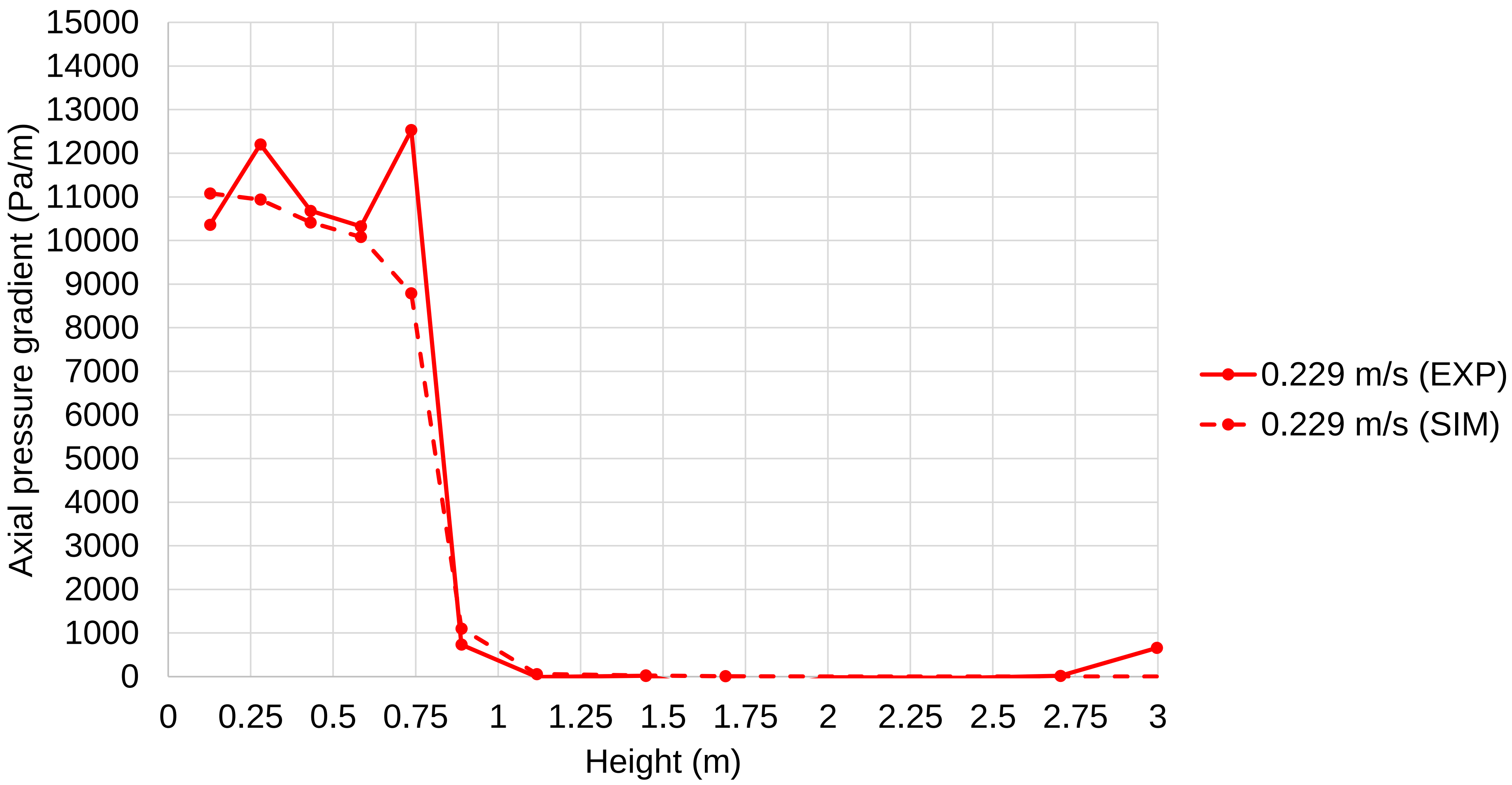
Axial pressure gradient



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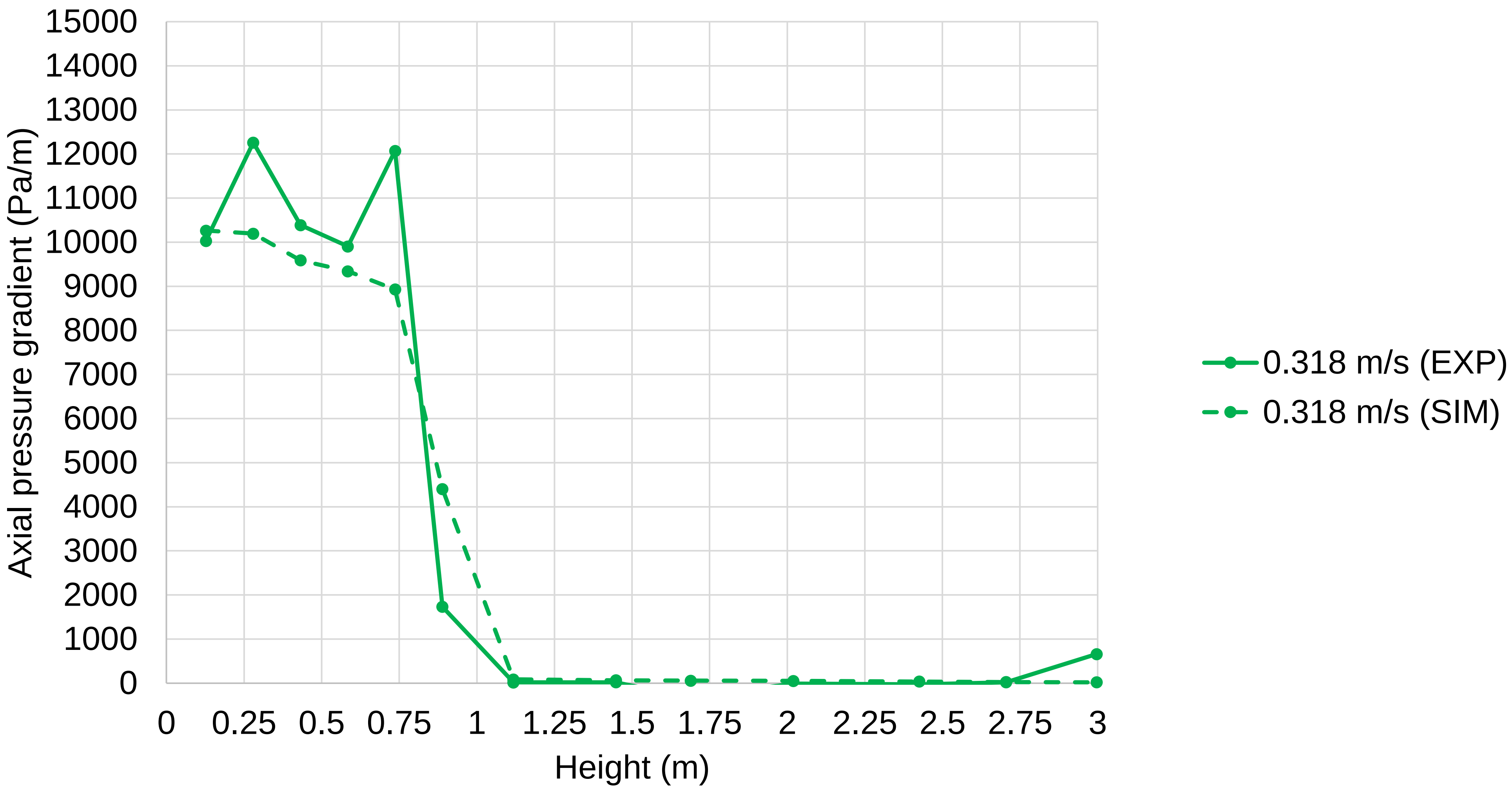
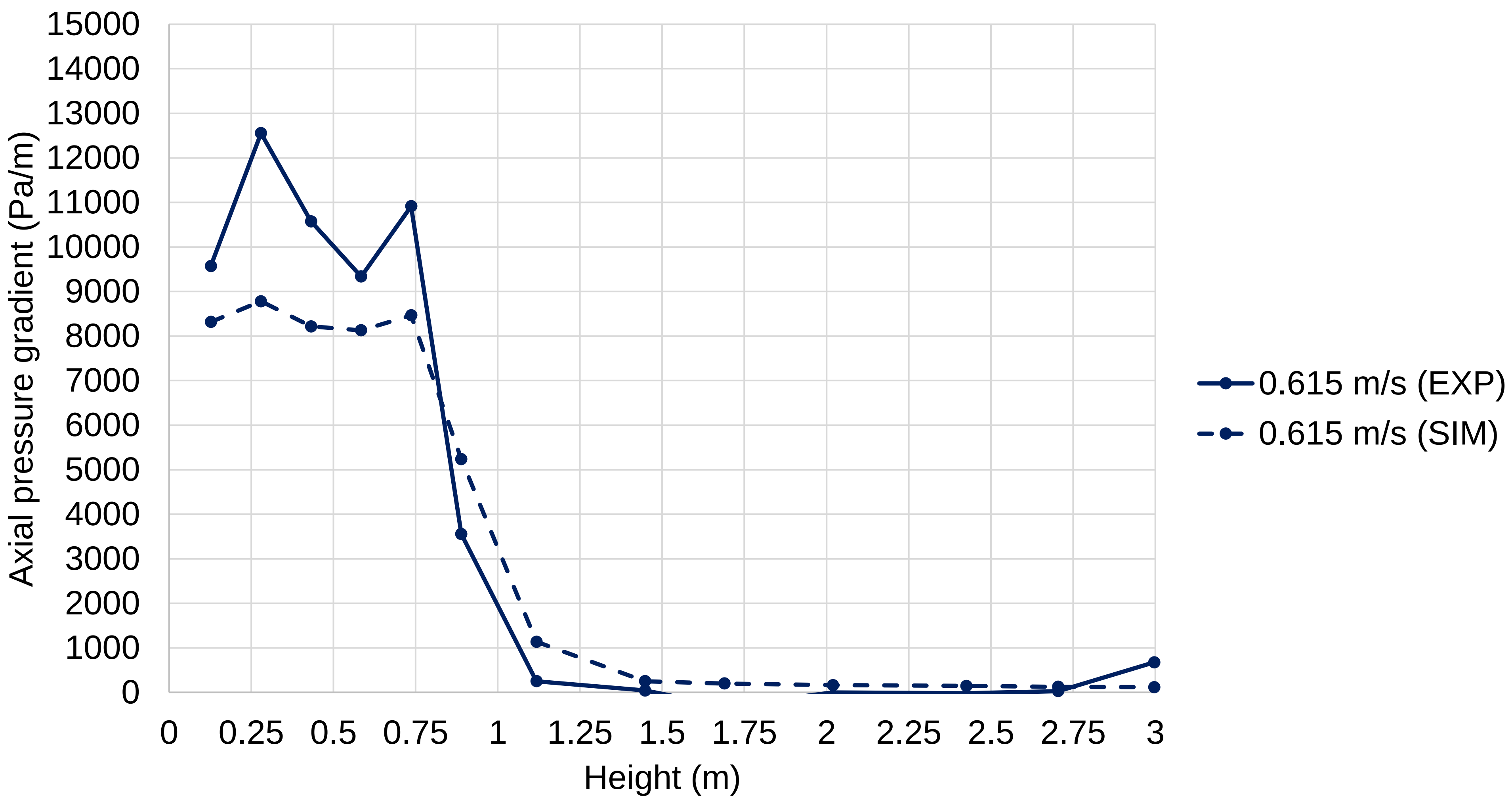
Axial pressure gradient



Axial pressure gradient



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Conclusion

- Drag correlation required to capture meso-scale effects
- Heterogeneous drag formulations e.g. EMMS as an alternative to Homogeneous drag
- EMP-GF produces reasonable results for the pressure drop gradient and bed expansion
- EMP-GF can generate results in less than two days
- Looking at bringing a similar experience to DEM

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Thank you