Turbulence modelling for gas-particle flows

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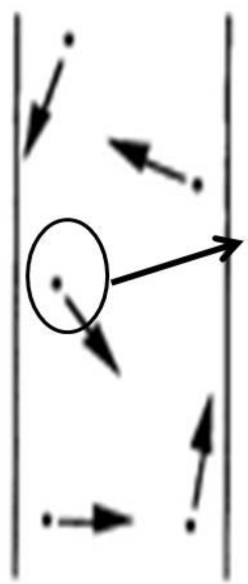
Outline

- An effort to understand the role of **Particle Phase Turbulence**
- Focus Applications: Downers and Risers
- Experimental Data**:** Lateral Segregation in Volume Fraction

Background

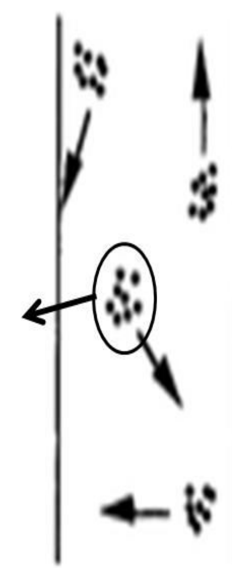
- Fox (2014)[#] stressed on the need to separate between turbulent kinetic energy and granular energy of particles

Individual Particle Scale



Fluctuations associated with granular temperature

Cluster Scale



Fluctuations associated with turbulent kinetic energy

[#] Fox, R.O. On multiphase turbulence models for collisional fluid-particle flows, JFM (742), 2014

Governing Equations: Particle Phase

- **Volume Fraction**

$$\frac{\partial\langle\alpha\rangle}{\partial t} + \nabla.\langle\alpha\rangle\langle u\rangle_p = 0$$

- **Momentum**

$$\frac{\partial\langle\alpha\rangle\langle u\rangle_p}{\partial t} + \nabla.\langle\alpha\rangle(\langle u\rangle_p\langle u\rangle_p + \langle u"u"\rangle_p + \langle P\rangle_p = \langle\alpha\rangle(\langle D\rangle_p + g)$$

$$\langle D\rangle_p = \frac{1}{\tau_d}(\langle u_f\rangle_f - \langle u\rangle_p + \frac{\langle\alpha' u_f'''\rangle}{\langle\alpha\rangle\langle 1-\alpha\rangle})$$

$$\langle\alpha' u_f'''\rangle = -\frac{\nu_{ft}}{Pr_t}\nabla\langle\alpha\rangle$$

Turbulent Dispersion Force

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Governing Equations: Particle Phase

- Granular Temperature

$$\frac{3}{2}[\frac{\partial\langle\alpha\rangle\langle\theta\rangle_p}{\partial t} + \nabla.\langle\alpha\rangle(\langle\theta\rangle_p\langle u\rangle_p + \langle u"\theta\rangle_p + \frac{2}{3}\langle q\rangle_p] = -\langle\alpha\rangle\langle P\rangle_p : \nabla\langle u\rangle_p$$

$$-\langle\alpha\rangle_p\langle P : \nabla u"\rangle_p - 12(1-e^2)\frac{\langle\alpha\rangle^2\rho_p g_0}{d_p\pi^{0.5}}\langle\theta\rangle^{\frac{3}{2}} - J$$

- Turbulent Kinetic Energy

$$\frac{\partial\langle\alpha\rangle k_p}{\partial t} + \nabla.\langle\alpha\rangle(k_p\langle u\rangle_p + \langle u" k_p\rangle\ \langle P.u"\rangle_p)$$

$$= -\langle\alpha\rangle\langle u" u"\rangle_p : \nabla\langle u\rangle + \langle\alpha\rangle_p\langle P : \nabla u"\rangle + \frac{\langle\alpha\rangle}{\tau_d}(\langle u".u_f'''\rangle_p - 2k_p)$$

$\rho_p\epsilon_p\alpha_p$

$2\langle\alpha\rangle\beta\sqrt{k_f k_p}$

→ **Interphase Turbulence Exchange**

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Governing Equations: Fluid Phase

- Turbulent Kinetic Energy

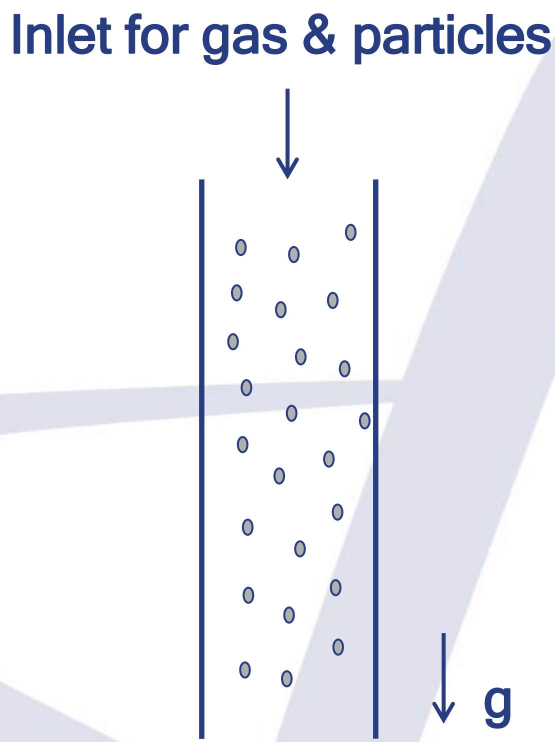
$$\frac{\partial\langle 1-\alpha\rangle k_f}{\partial t} + \nabla.\langle 1-\alpha\rangle(k_f\langle u_f\rangle_f) - \nabla.(\nu_f + \frac{\nu_{ft}}{\sigma_f})\nabla k_f = \langle 1-\alpha\rangle\Pi_f + \frac{\rho_p\langle\alpha\rangle}{\rho_f\tau_d}((\langle u\rangle_p - \langle u_f\rangle_f)^2 + \langle u'' . u_f'''\rangle_p - 2k_f) - \langle 1-\alpha\rangle\epsilon_f$$

$$\frac{\rho_p\langle\alpha\rangle}{\rho_f\tau_d}(\langle u\rangle_p - \langle u_f\rangle_f)^2$$

Turbulence induced due to the presence of particles

Downer

- Experimental Details[#]
  - Co-current down flow
  - Height of Column: 7 m
  - Diameter of Column: 0.14 m
  - Density of Particles: 1545 Kg/m3
  - Diameter of Particles: 54 μm
  - Density of Gas: 1.18 Kg/m3
  - Gas Viscosity: 1.8 e-5 Pas
  - Superficial Gas Velocity: 4.33 m/s
  - Inlet Solid Flow Rate: 70 Kg/m^2-s



Wang et al. Powder Technology (70), 1992, 271-275

Downer

- Problem Set-up
  - Mesh: 70x70
  - Radial Distribution Function: Ding-Gidaspow
  - Particle Viscosity: Gidaspow
  - Granular Conductivity: Gidaspow
  - Drag Model: Wen and Yu
  - Wall treatment: No-slip for gas and Slip for particles

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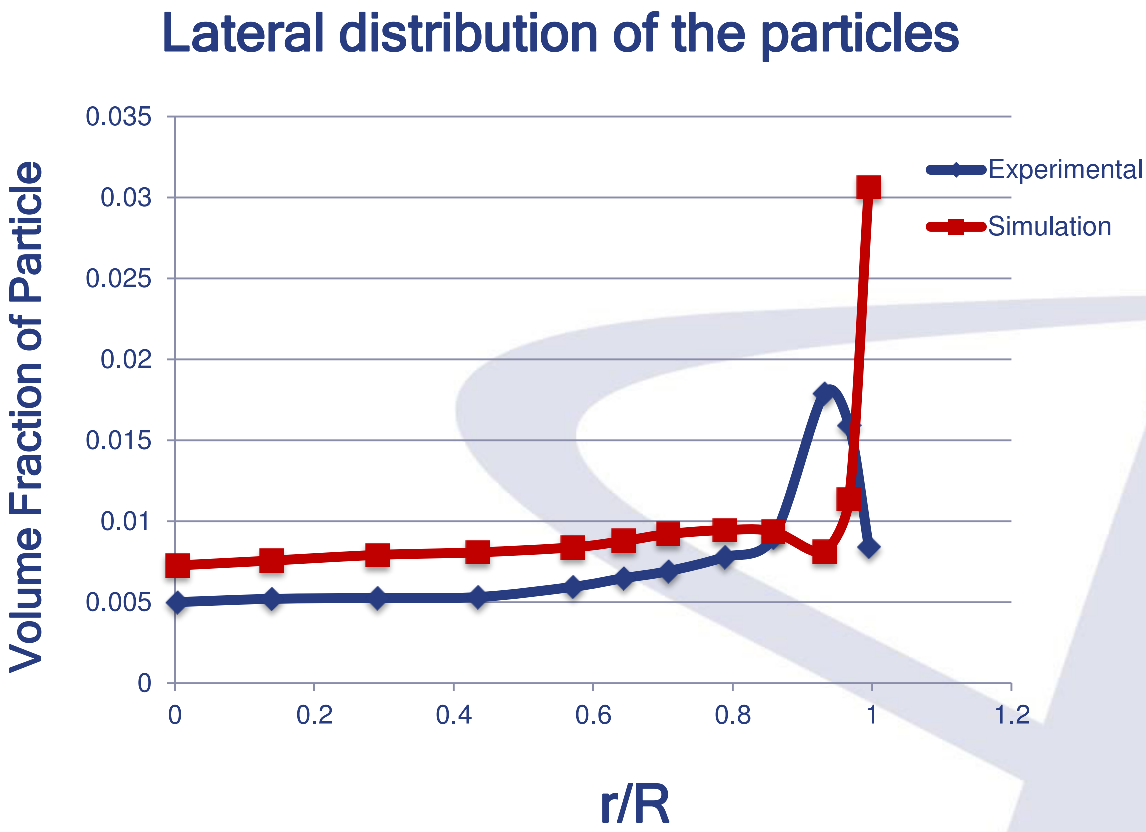
Downer: Results

Simulation without considering particle phase turbulence



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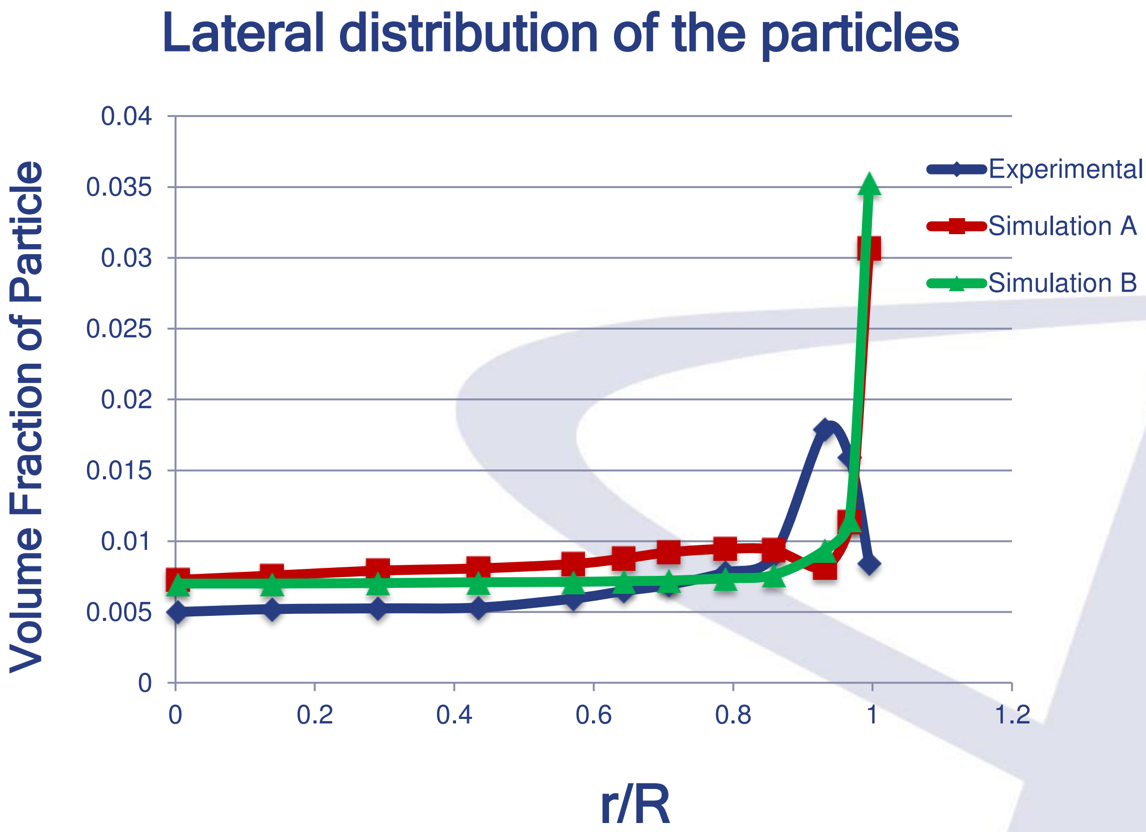
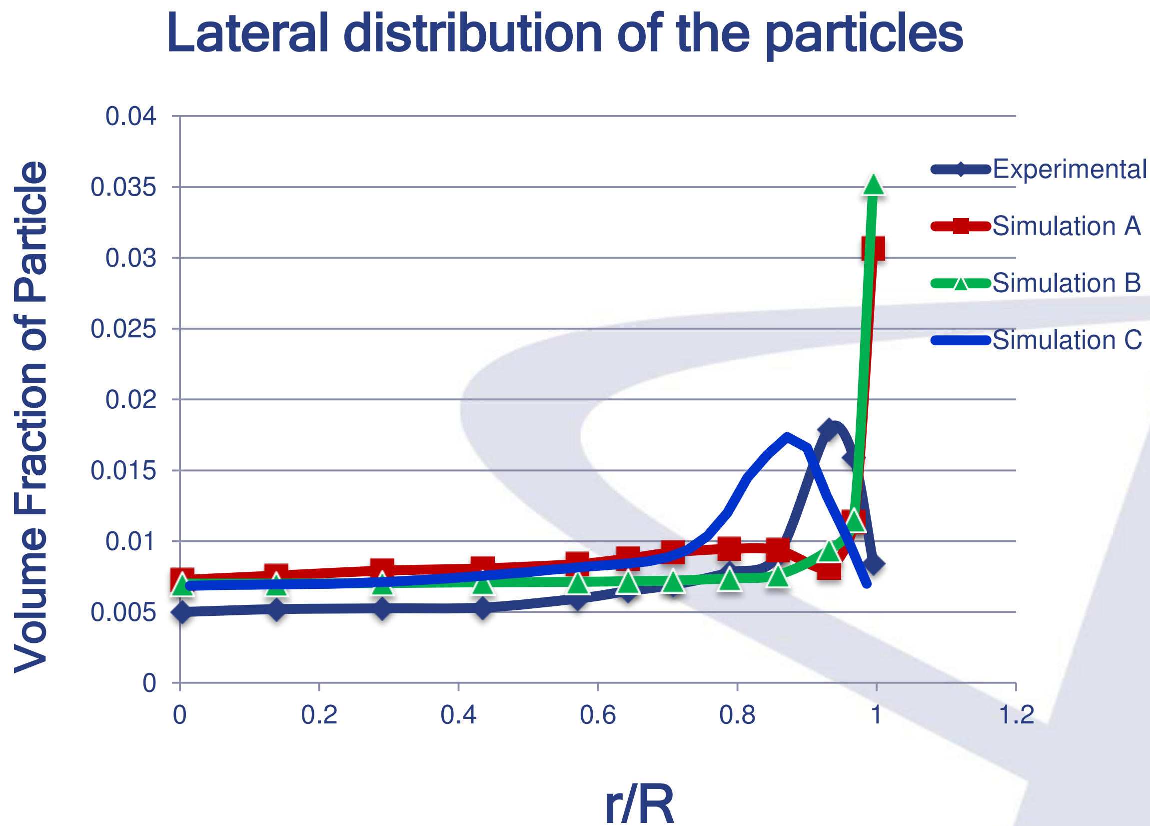
Downer: Results

Simulation with particle phase turbulence – no exchange



Downer: Results

Simulation with particle phase turbulence – exchange accounted



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Downer: Turbulent Kinetic Energy Exchange

$$\langle\alpha\rangle(\langle u".u_f'''\rangle_p) = \langle\alpha u".u_f'''\rangle = 2\langle\alpha\rangle\beta\sqrt{k_f k_p}$$

Fluid Phase:

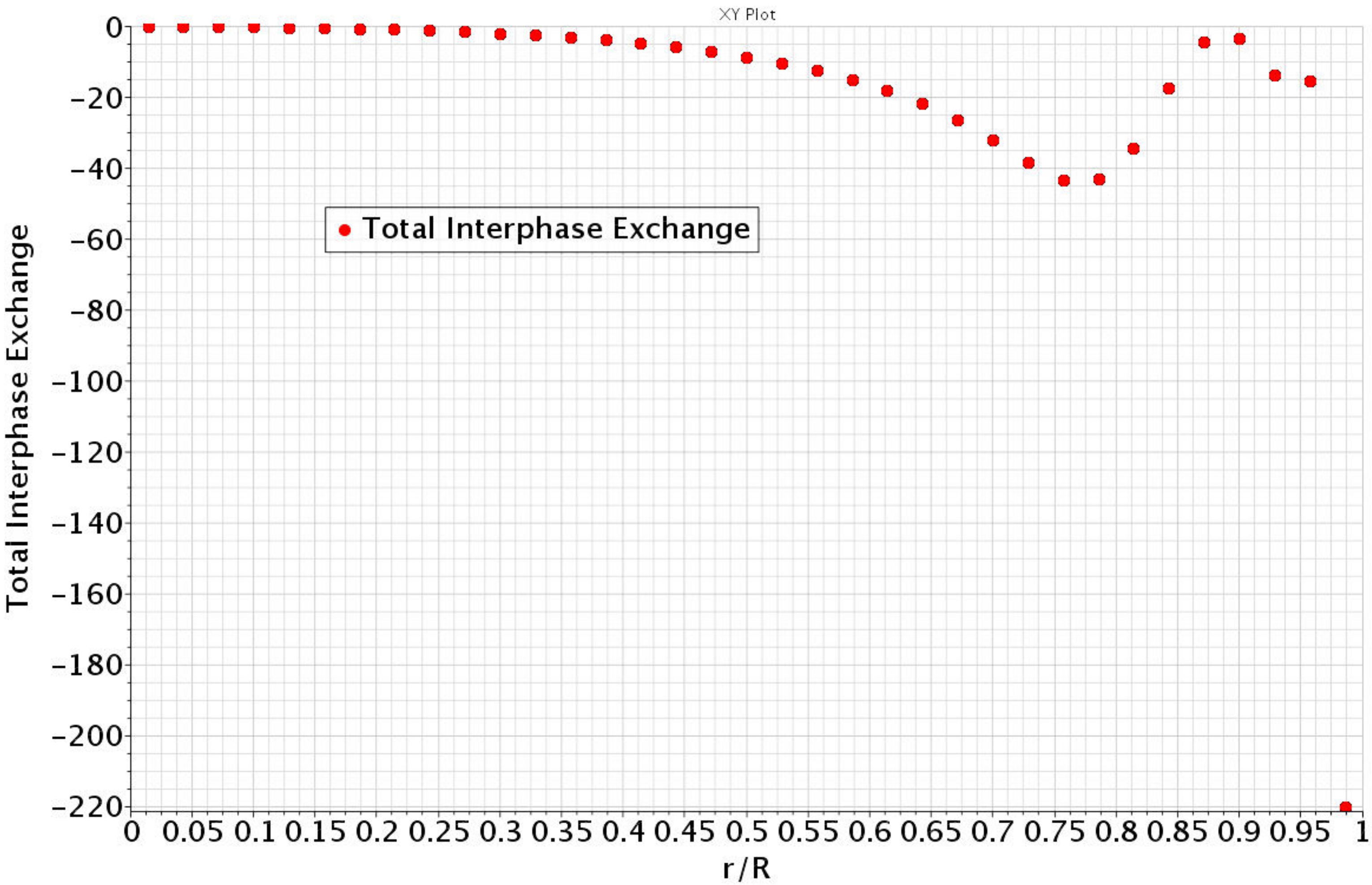
$$2\langle\alpha\rangle\frac{\rho_p}{\rho_f\tau_d}(\beta\sqrt{k_f k_p} - k_f)$$

+ Net Dissipation of Turbulent Kinetic Energy

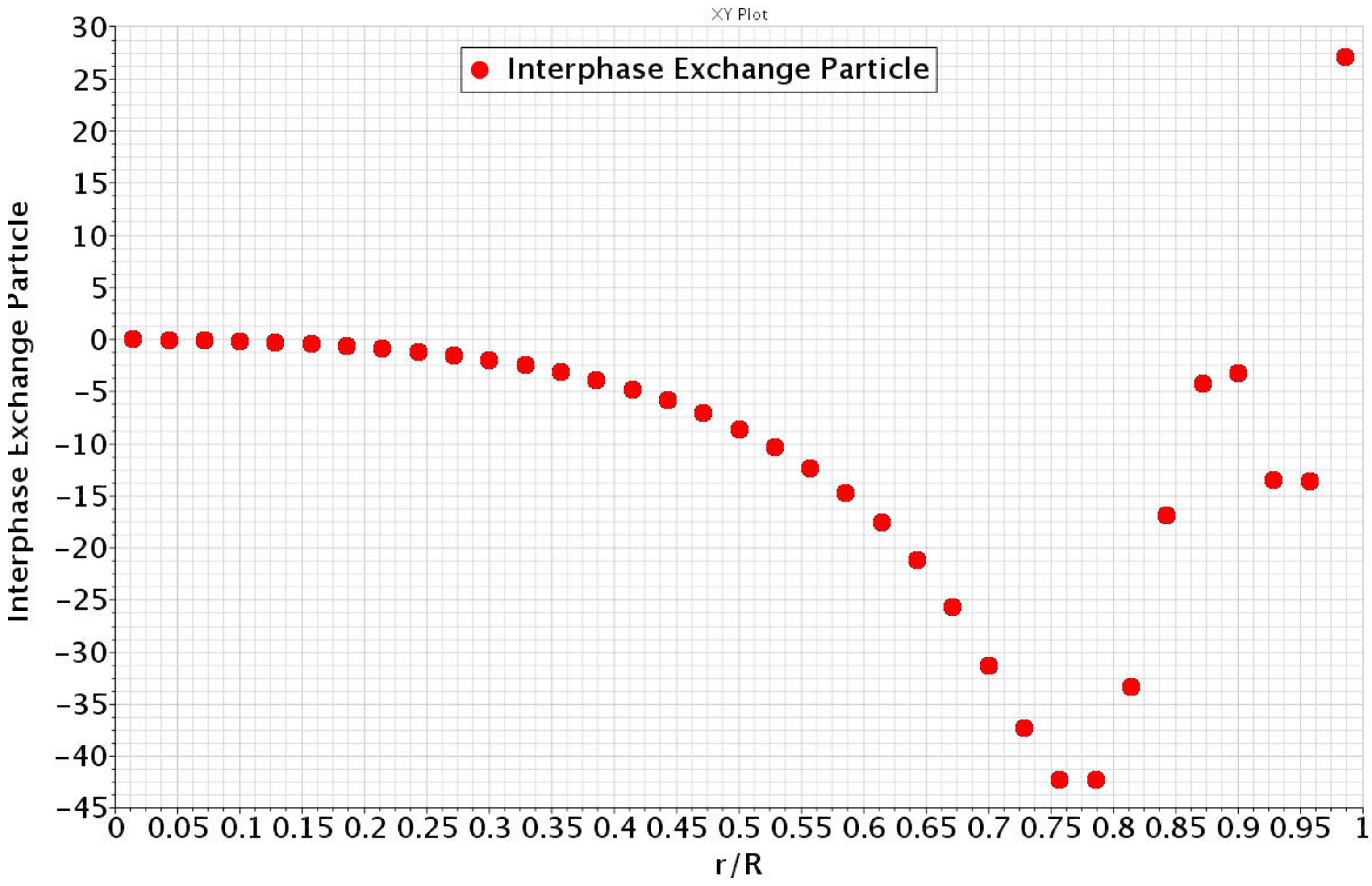
Particle Phase:

$$2\frac{\langle\alpha\rangle}{\tau_d}(\beta\sqrt{k_f k_p} - k_p)$$

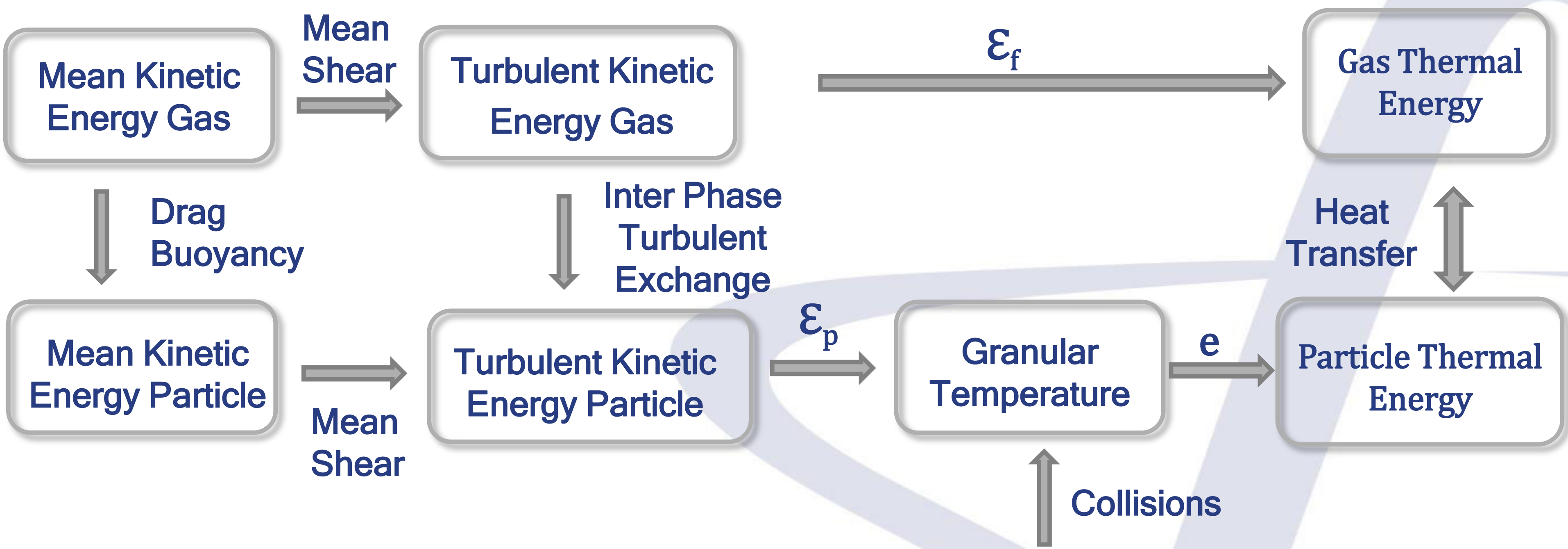
Downer: Turbulent Kinetic Energy Exchange



Downer: Turbulent Kinetic Energy Exchange

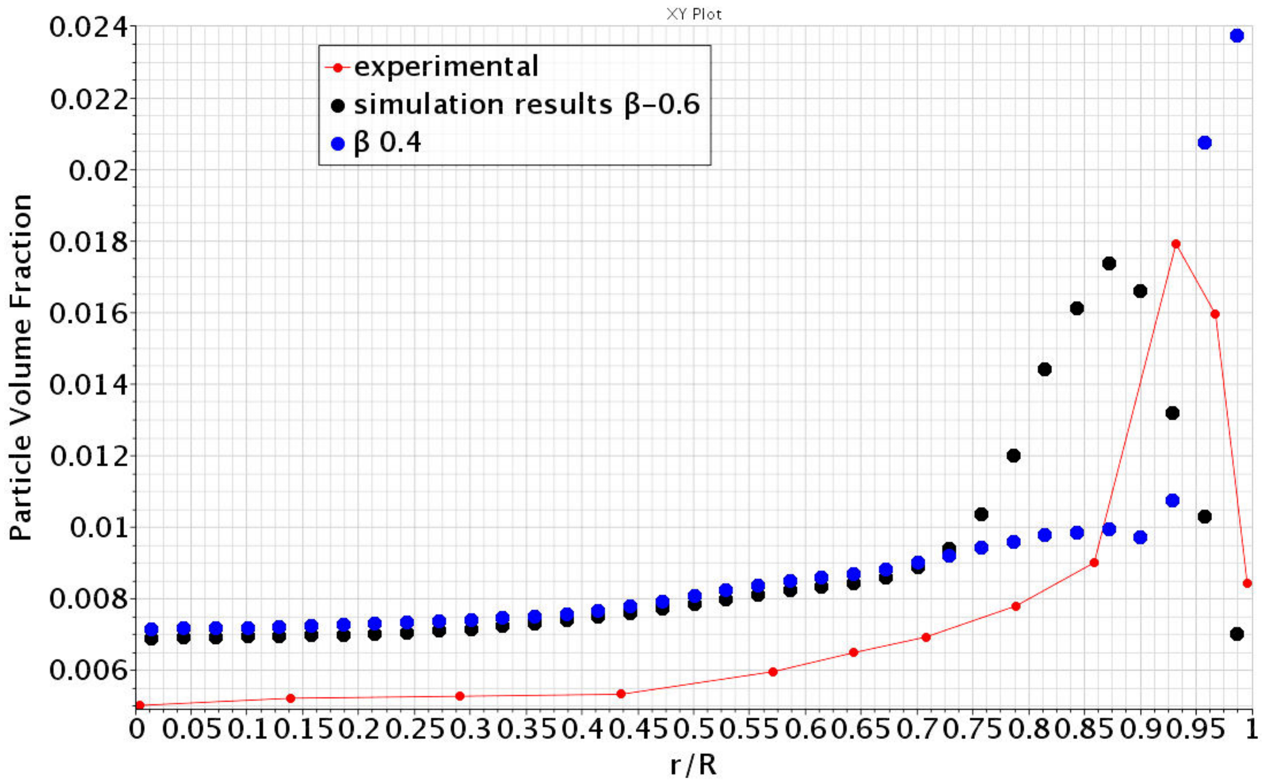


Energy Flow Diagram



Downers: Parametric Study for beta

Lateral distribution of the particles



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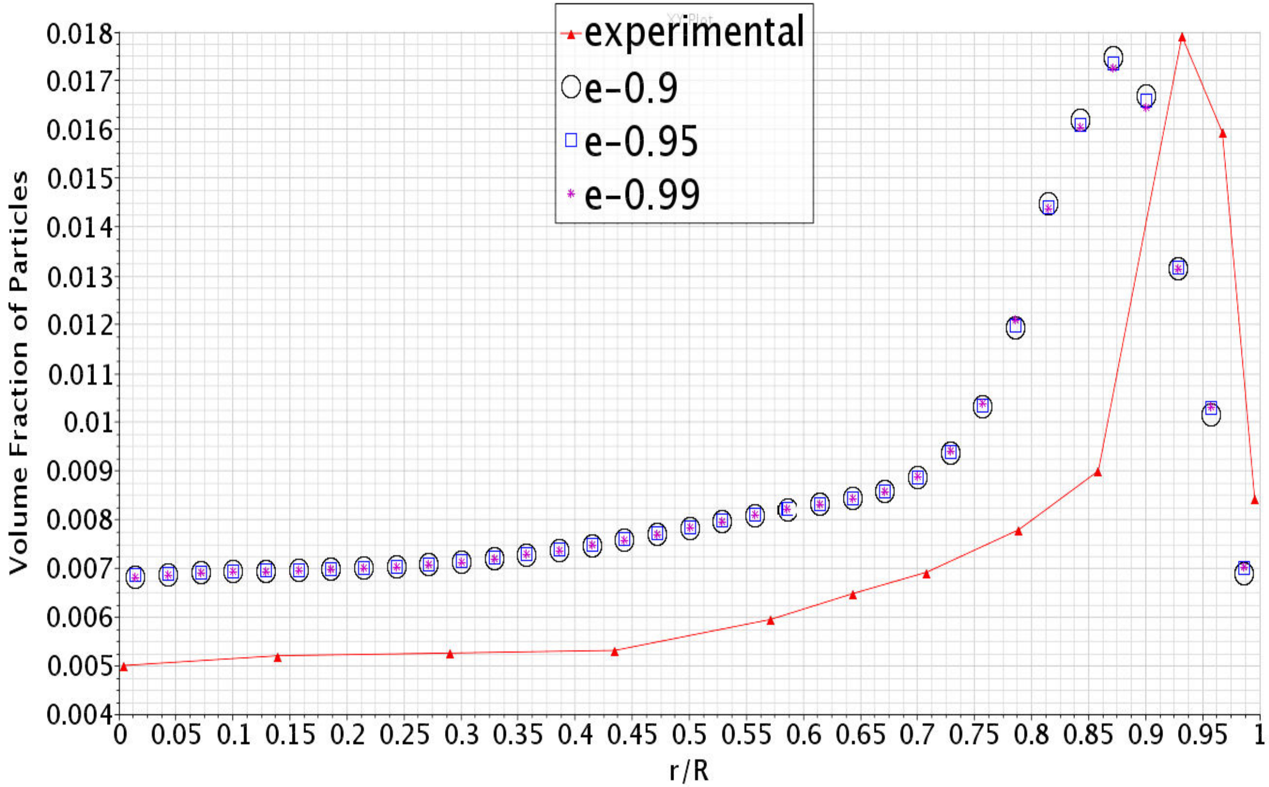
Downers: Parametric Study for restitution coefficient

Lateral distribution of the particles



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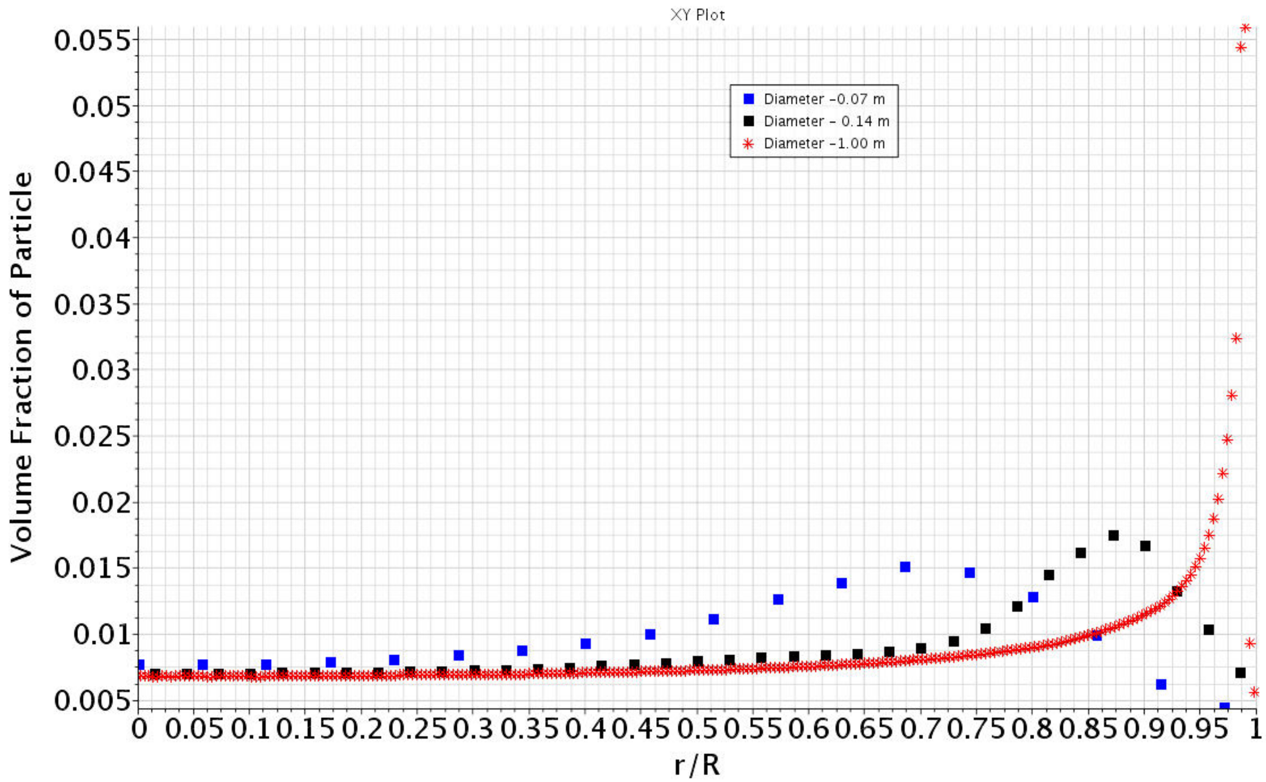
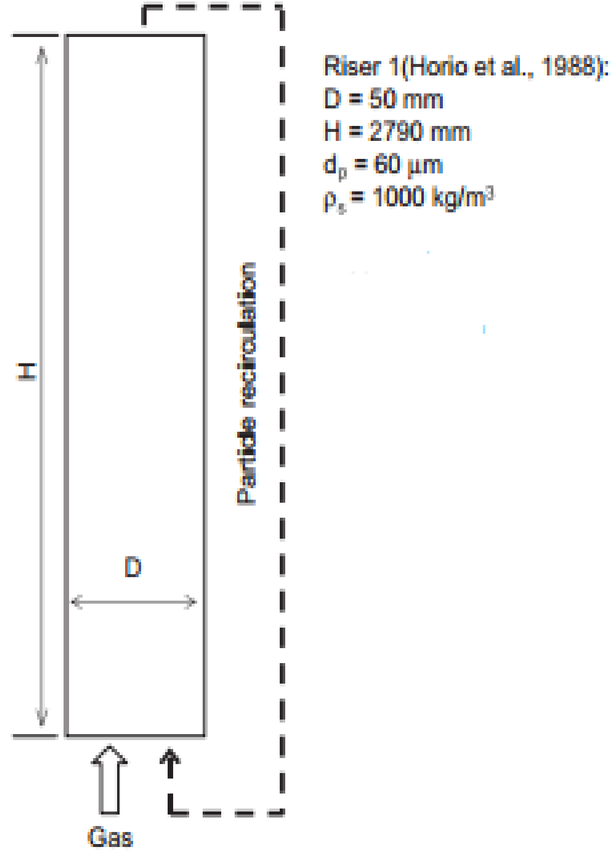
Downers: Scale up investigation

Lateral distribution of the particles



Riser

- Experimental Details
  - Circulating Fluidized Bed
  - Density of Gas: 1.18 Kg/m3
  - Gas Viscosity: 1.8 e-5 Pas
  - Superficial Gas Velocity: 1.29 m/s
  - Inlet Solid Flow Rate: 11.71 Kg/m^2-s



- Problem Set-up
  - Mesh: 80x430
  - Radial Distribution Function: Ding-Gidaspow
  - Particle Viscosity: Syamlal
  - Granular Conductivity: Syamlal
  - Drag Model: EMMS
  - Wall treatment: No-slip for gas and Slip for particles

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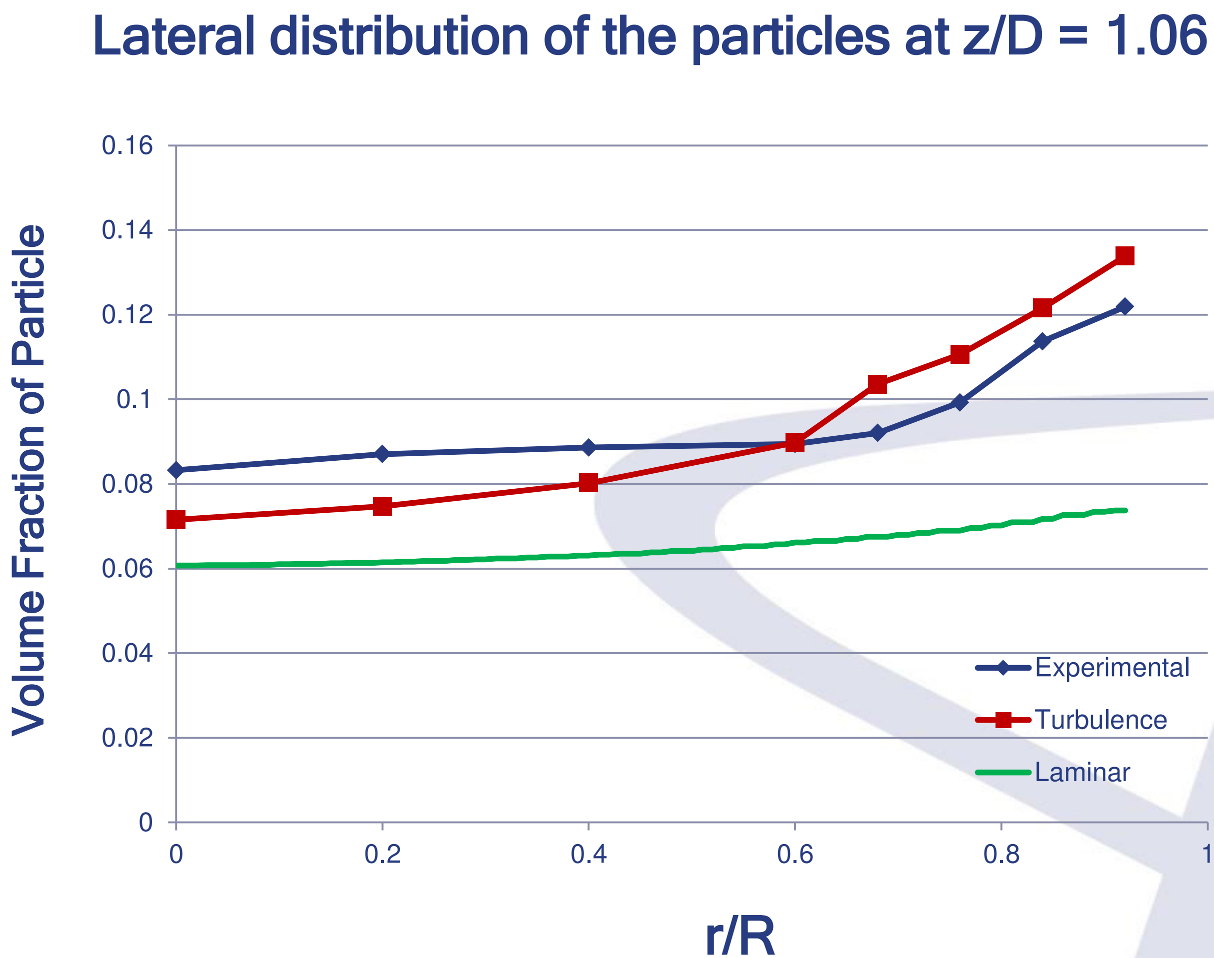
Riser: Results



Thank You!