Numerical Investigations of the transport of submerged insulation particle

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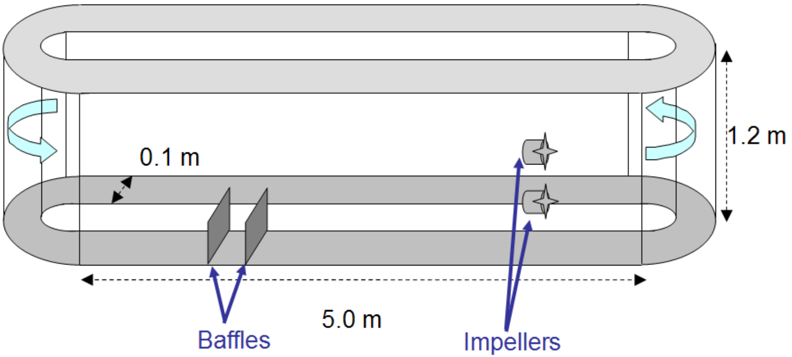
23^{rd} May 2007

Sedimentation and resuspension of submerged particles in a horizontal flow

- Experimental study uses



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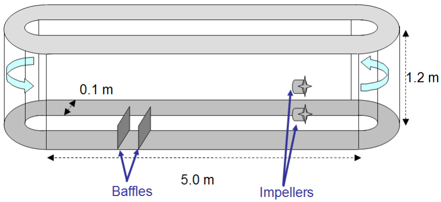
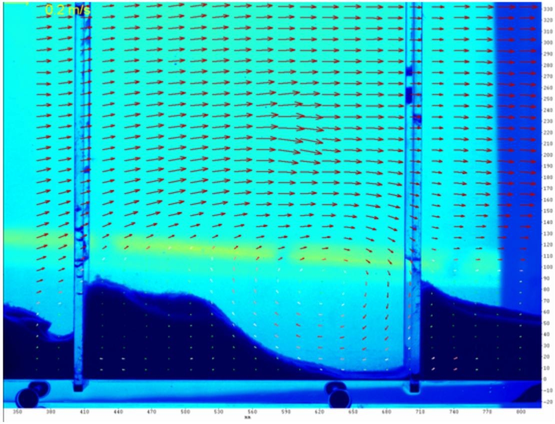
  - High-speed video





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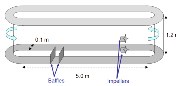
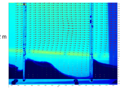
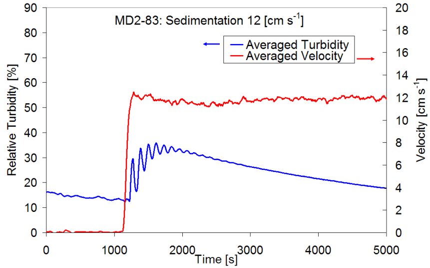
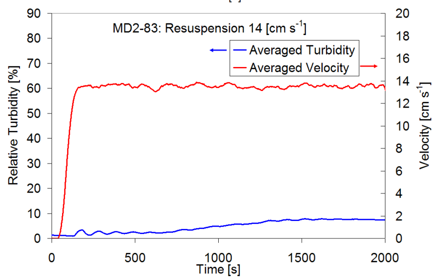
  - Pertinent concentrations









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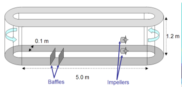
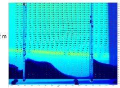
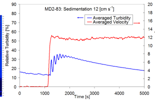
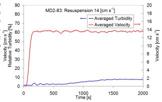
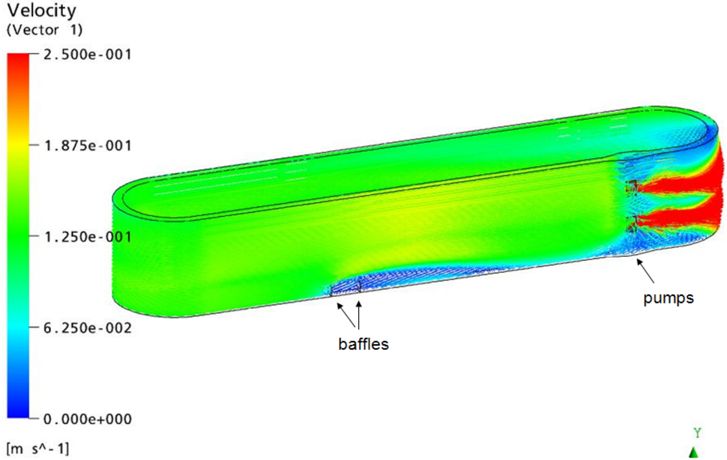
- Numerical study can examine
  - Whole channel











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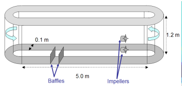
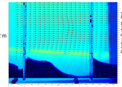
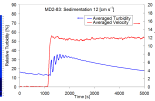
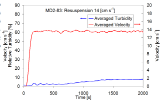
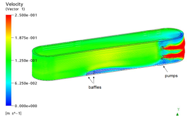
  - Channel section upstream of the impeller

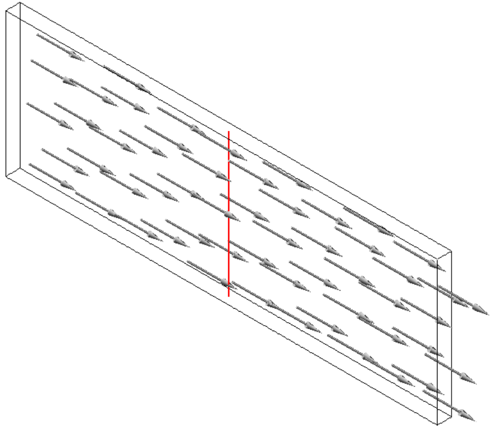












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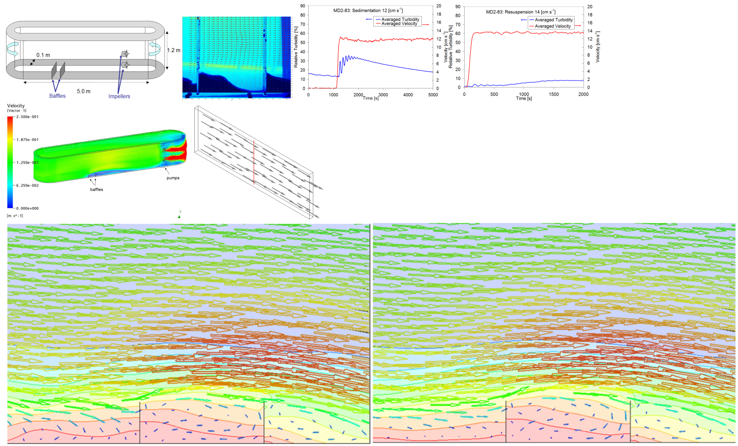

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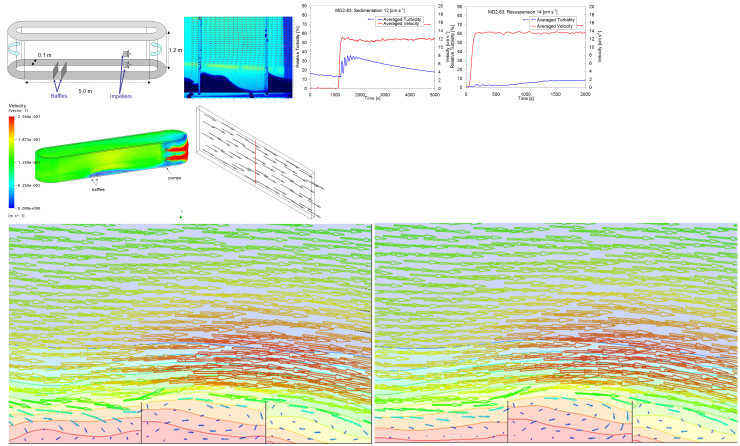
- To determine the impact of
  - Local velocity field
  - Local concentration profiles
  - Viscosity
  - Buoyancy, drag and turbulence dispersion forces



Sedimentation and resuspension of submerged particles in a horizontal flow

- Eulerian-Eulerian multiphase flow

Sedimentation and resuspension of submerged particles in a horizontal flow

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  - Relative and mixture (2) and (3)
  - Dispersed phase eddy viscosity (5)
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- Boundary and initial conditions 1

The virtual particle

- Particles can be classified by
  - + sphericity
  - + compactness
  - + convexity

Class Particles

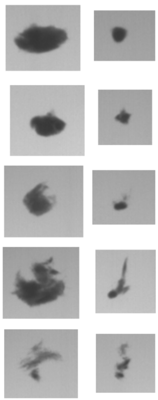
1

2

3

4

5



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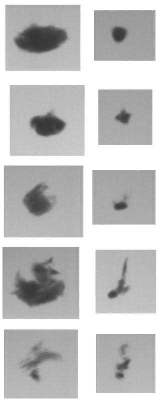
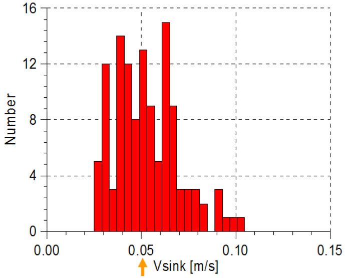


- Measured distribution of agglomerate velocities



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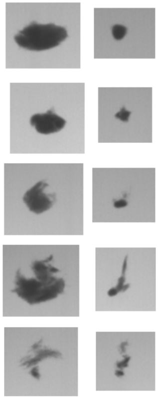

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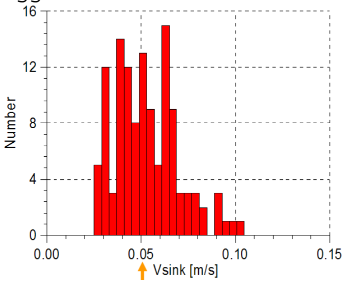

- Mean terminal velocity of particles 0.05 m s^{-1}

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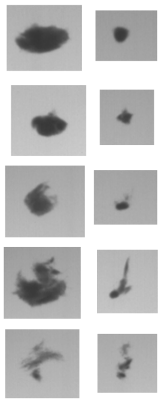

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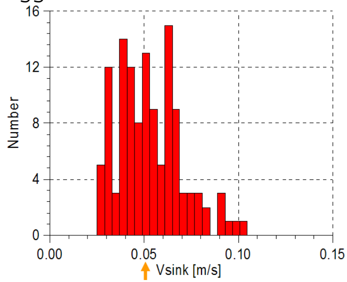
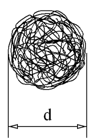


- Mean terminal velocity of particles 0.05 m s^{-1}
- Assumed spherical agglomerate of fibres



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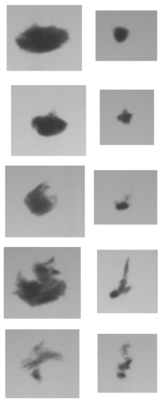

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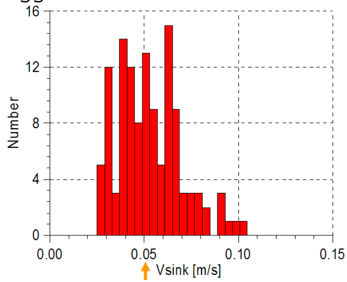

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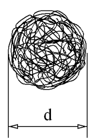

- Drag = Buoyancy

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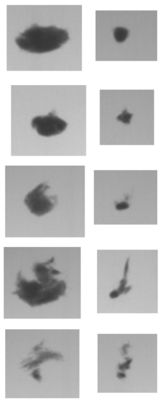

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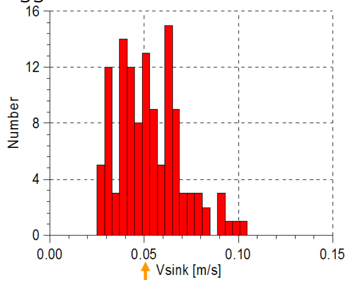

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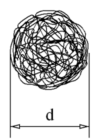

- Drag = Buoyancy
- Iteratively resolve C_D

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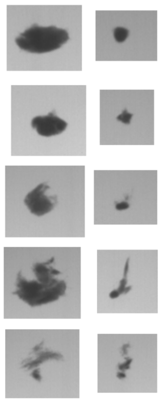

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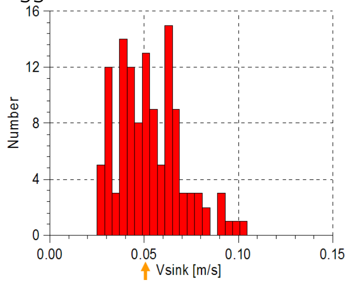

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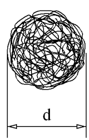

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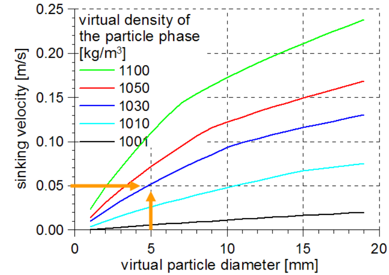
- Or use



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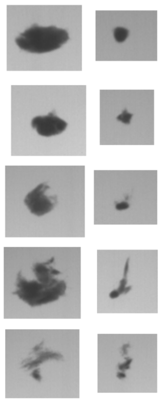

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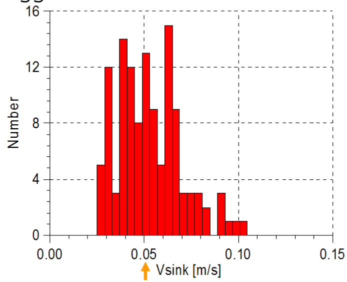

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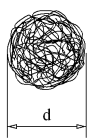

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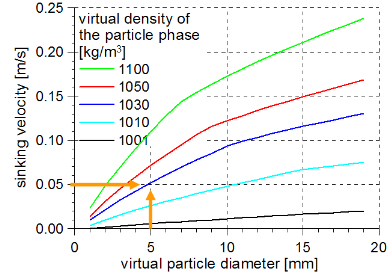

- Terminal velocity ≡ measured mean velocities was obtained
  - $d_p = 5$ mm
  - $\rho_c = 997$ kg m^{-3}
  - $\rho_f = 2800$ kg m^{-3}
  - $\rho_p = 1030$ kg m^{-3}

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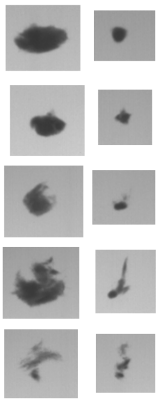

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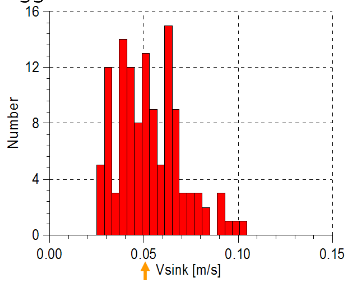

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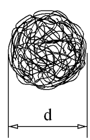

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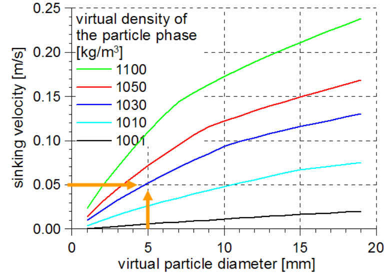

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- This also gives a particle share of 0.018

$$\alpha_p = \frac{\rho_p - \rho_c}{\rho_f - \rho_c} \tag{1}$$

Viscosities

- Mixture and relative viscosities

$$\mu_{cp} = \mu_c \mu_r \tag{2}$$

$$\mu_r = 1 + \begin{cases} 0 & r_p < 0.6 \\ r_p^3 10^4 & r_p \geq 0.6 \end{cases} \tag{3}$$

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- Continuous phase eddy viscosity

$$\nu_{tc} = c_\mu \frac{k_c^2}{\varepsilon_c} \tag{5a}$$

$$\nu_{tc} = \frac{c_\mu^{0.5} k_c}{f_{\max}\left(c_\mu^{0.5}\omega_c, 2\tau_{ij}\tanh\left[f_{\max}\left(\frac{2k_c^{0.5}}{c_\mu \omega_c y}, \frac{500\nu_c}{y^2\omega_c}\right)^2\right]\right)} \tag{5b}$$

$$\tau_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \tag{6}$$

Buoyancy and interfacial forces

- Buoyancy force

$$S_{cp}^{B} = \mathbf{g} r_p \left(\rho_p - \rho_c\right) \quad (7)$$

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- Drag Force

$$M_{cp}^{D} = \frac{3}{4}\frac{C_D}{d_p} r_p \rho_c \left|\mathbf{U}_p - \mathbf{U}_c\right| \left(\mathbf{U}_p - \mathbf{U}_c\right) \tag{8}$$

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- C_D was estimated by using the Schiller-Naumann drag correlation
- Particle Reynolds number $Re_p = d_p U_{np}/\nu_c$ was based on the terminal or relative velocities

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Buoyancy and interfacial forces

- Buoyancy force

$$S_{cp}^{B} = \mathbf{g} r_p \left(\rho_p - \rho_c\right) \tag{7}$$

- Drag Force

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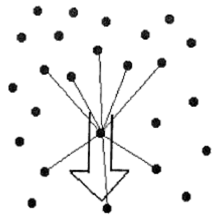
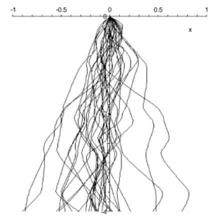
$$M_{cp}^{TD} = C_{TD} \frac{3}{4}\frac{C_D}{d_p} r_p \rho_c \left|\mathbf{U}_p - \mathbf{U}_c\right| \frac{\nu_{tc}}{\sigma_{tc}} \left(\frac{\nabla r_p}{r_p} - \frac{\nabla r_c}{r_c}\right) \tag{11}$$

Turbulent dispersion force





Wikipedia::Galilean Transformation *Journal of Engineering Mathematics* **41:** 259–274, 2001. D.A. Drew / Nuclear Engineering and Design 235 (2005) 1117–1128

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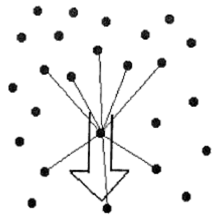
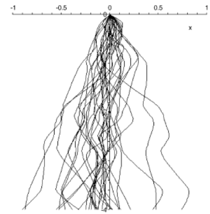
Turbulent dispersion force





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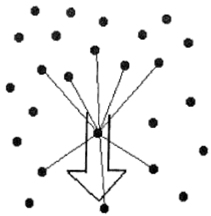
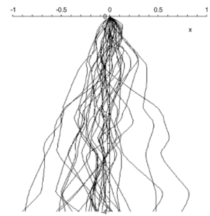
Turbulent dispersion force





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- Characterises deviations in particle trajectories caused by turbulent eddies
- Particle transport can be considered as an averaged phenomena
- Spread or dispersion of particles is dependent on:
  - Particle response time
  - Timescale of turbulent eddies
  - Gradient of the volume fraction with respect to spatial variation
  - Gradient of the volume fraction with respect to velocity variation

Boundary and initial conditions

Condition	Velocity (m s^{-1})	Re_{Ch} ✗	Re_{Ch} ✓	Re_p	r_p
A	0.01	616	2037	112	0.0414
B	0.10	6162	20370	560	0.0414
C	0.50	30810	101850	2801	0.0414

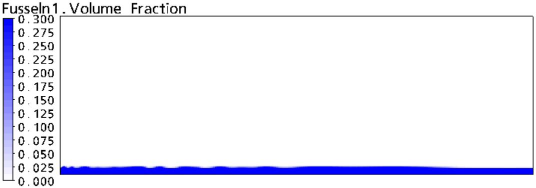
Transition to turbulence occurs over the range 4000-11000 of the channel Reynolds number

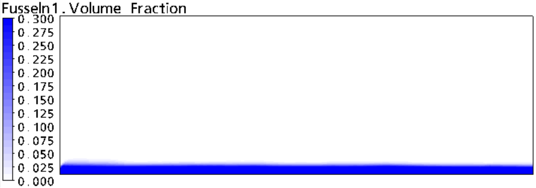
Model	M_{cp}^{TD}	C_{TD}
1	No force	0
2	(10)	$\frac{\beta_L}{\beta_p}\frac{\beta_L}{\beta_L+\beta_p}$
3	(11)	1

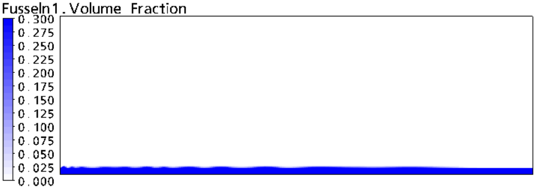
Where β_p and β_L are the particle relaxation time and the Lagrangian time–scale

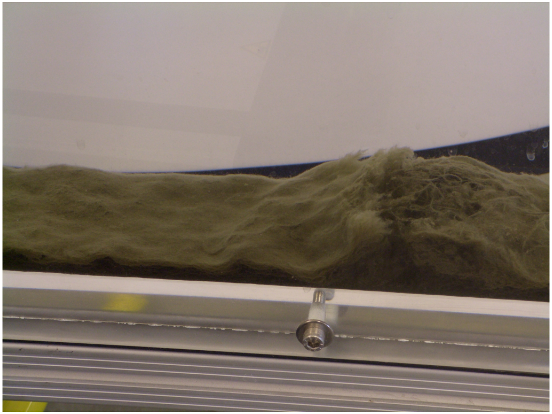
Volume fraction contours at condition A

	1A	1B	1C	2A	2B	2C	3A	3B	3C
Re_{Ch}	2037	20370	101850	2037	20370	101850	2037	20370	101850
M_{cp}^{TD}	0	0	0	(10)	(10)	(10)	(11)	(11)	(11)

1A


2A


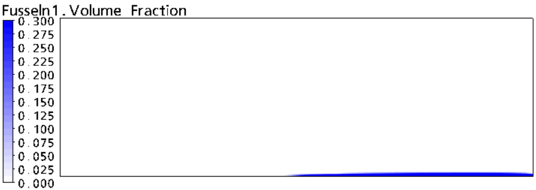
3A




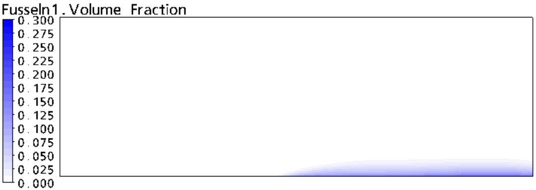
Volume fraction contours at condition B

	1A	1B	1C	2A	2B	2C	3A	3B	3C
Re_{Ch}	2037	20370	101850	2037	20370	101850	2037	20370	101850
M_{cp}^{TD}	0	0	0	(10)	(10)	(10)	(11)	(11)	(11)

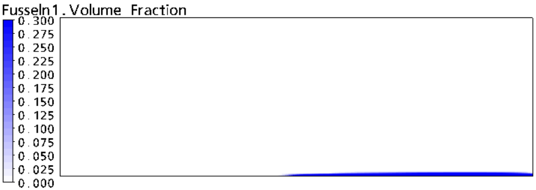
$1B$



$2B$

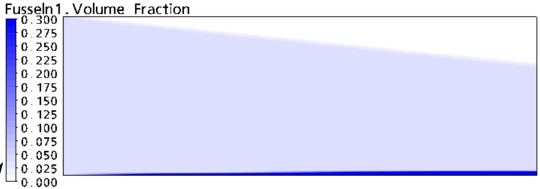


$3B$

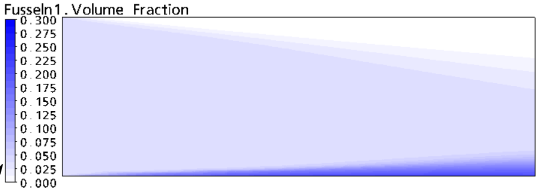


Volume fraction contours at condition C

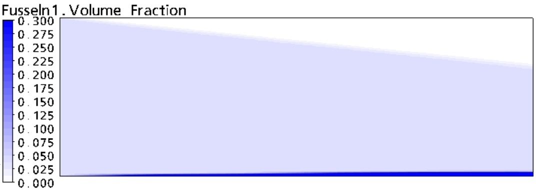
	1A	1B	1C	2A	2B	2C	3A	3B	3C
Re_{Ch}	2037	20370	101850	2037	20370	101850	2037	20370	101850
M_{cp}^{TD}	0	0	0	(10)	(10)	(10)	(11)	(11)	(11)



$1C$



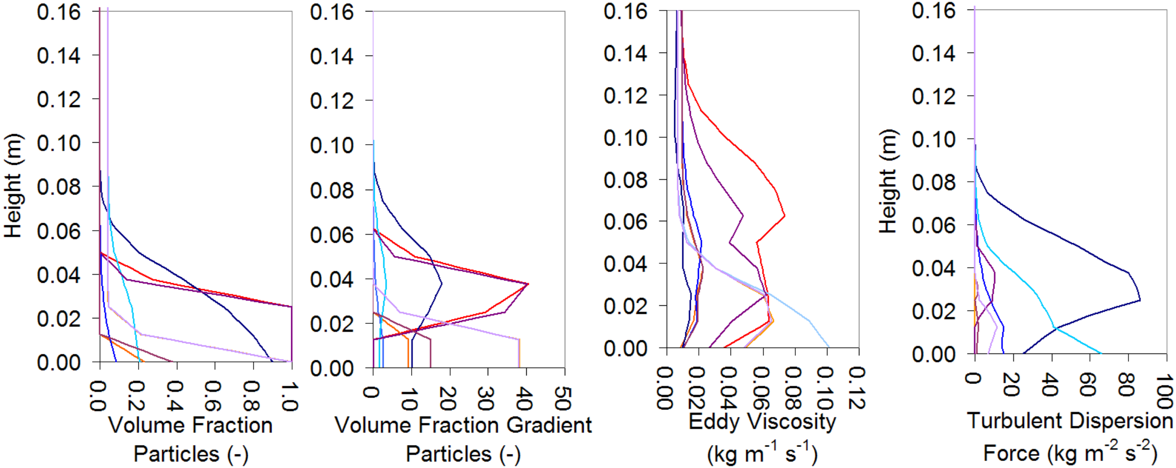
$2C$



$3C$

Gradient profiles

	1A	1B	1C	2A	2B	2C	3A	3B	3C
Re_{Ch}	2037	20370	101850	2037	20370	101850	2037	20370	101850
M_{cp}^{TD}	0	(10)	(11)	0	(10)	(11)	0	(10)	(11)
	—	—	—	—	—	—	—	—	—



Conclusions

- Qualitatively correct phenomena observed at different velocity conditions

Future work

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  - Appropriate boundary conditions and phase definitions
- Scale-up to containment vessel size simulations and experiments
- Increase model complexity to incorporate more phenomena
  - Particle size distributions and agglomeration and fragmentation
  - Multiphase interactions (gas-liquid-solid) with descending hot water jets

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