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PA-Sitzung

ODIN PROJECT: MODELING AND SIMULATION OF PARTICLES IN THE MULTIPHASE FLOWS IN OPENFOAM®

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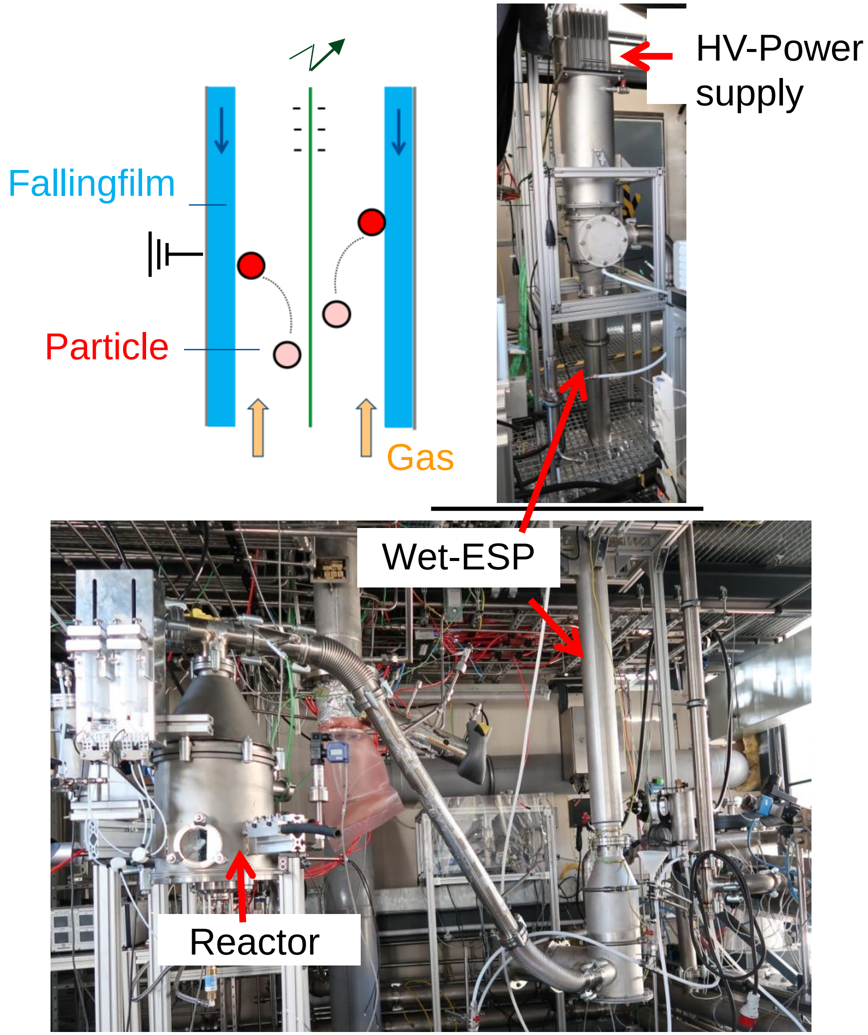
AiF Mitglied



Reactor - Wet Electrostatic Precipitator unit

Background:

- ❑ Processing/application of Nanomaterials (NMs) as
  - ❖ Dispersion (e.g., paints/lacquers, surface coatings)
  - ❖ Adsorption (e.g., foam/emulsion, well characterized films)

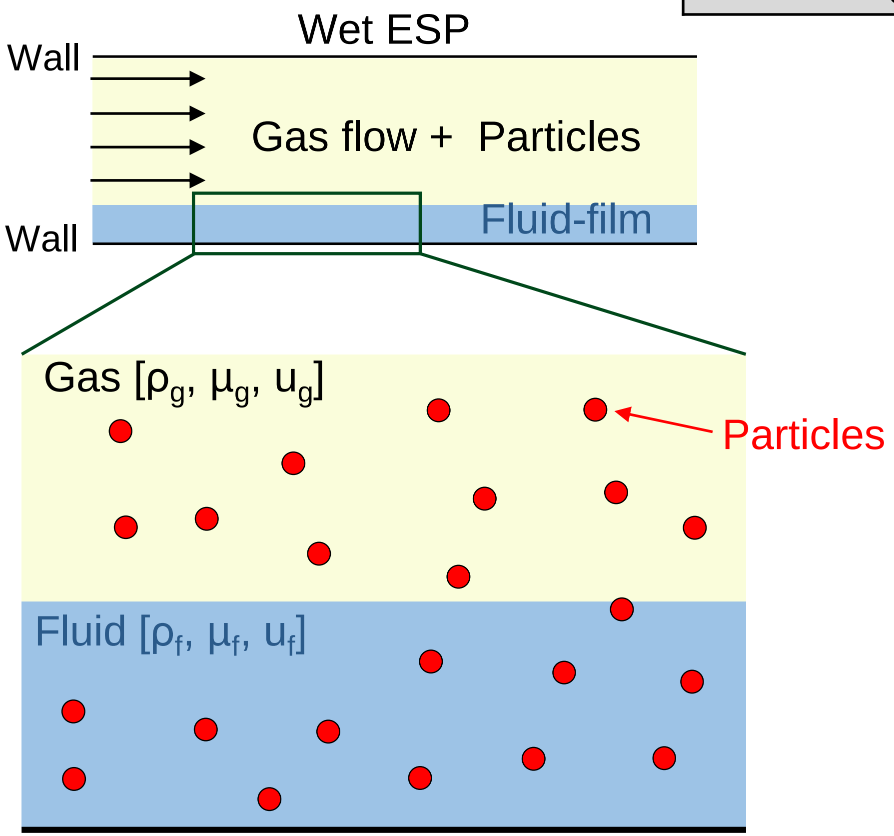
Problem:

- ❑ The gas-borne NMs are required to transfer into liquid phase for both safety and further processing reasons

Aim:

- ❑ Create a solver in OpenFOAM to simulate the **particle cloud in the multiphase flow**
- ❑ Further develop the solver for various forces acting on particles
- ❑ Simulate the gas-borne particle transmission from the gas phase into the liquid (or falling film) phase

Multiphase Fluids Particle Interaction Solver



	Liquid	Gas	Particle Cloud
Phase	Continuum	Continuum	Discrete
Modelling approach	Eulerian	Eulerian	Lagrangian

Solvers based on VOF (Liquid, Gas) — Library (Particle Cloud)

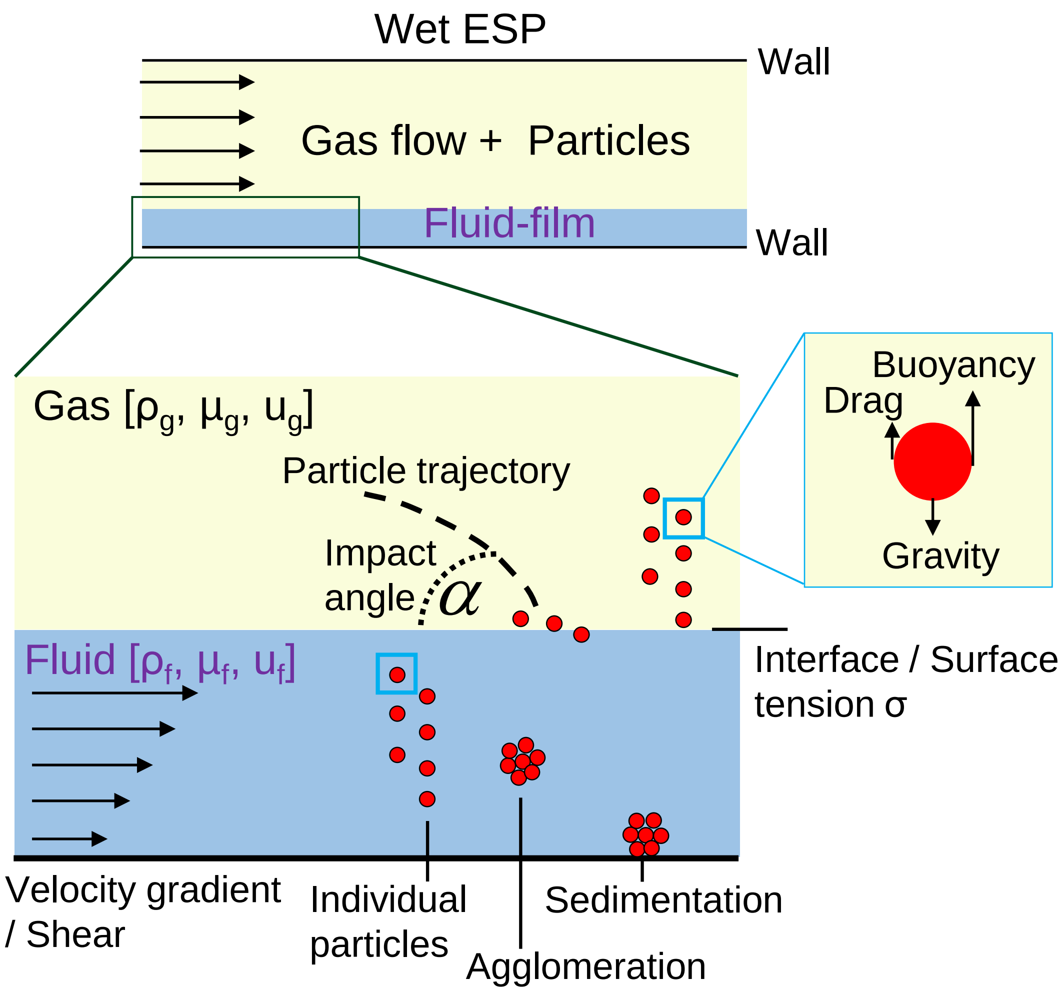
interFOAM solver + Lagrangian Particle Tracking

*Solver for 2 incompressible, isothermal immiscible fluids using a **VOF** method*

Volume **o**f **F**luid **L**agrangian **P**article **T**racking (**VoFLPTFoam**)

to simulate the ***M**ultiphase **F**luids-**P**article **I**nteraction (MFPI)*

MFPI Solver – Mathematical modeling



Fluid phases (VoF - Euler approach)

- Shared velocity field is solved simultaneously with the continuity and momentum equations:

$$\nabla \bullet \mathbf{U} = 0$$

$$\frac{\partial(\rho \mathbf{U})}{\partial t} + \nabla \bullet (\rho \mathbf{U}\mathbf{U}) - \nabla \bullet (\mu \nabla \mathbf{U}) - (\nabla \mathbf{U}) \bullet \nabla \gamma = -\nabla p_d - \mathbf{g} \bullet \mathbf{x} \nabla \rho + \sigma \kappa \nabla \gamma$$

- Interface is captured by solving an additional equation for the phase fraction: $\frac{\partial \gamma}{\partial t} + \nabla \bullet (\mathbf{U}\gamma) + \nabla \bullet [\mathbf{U}_r \gamma (1-\gamma)] = 0$

Particles (Lagrange approach)

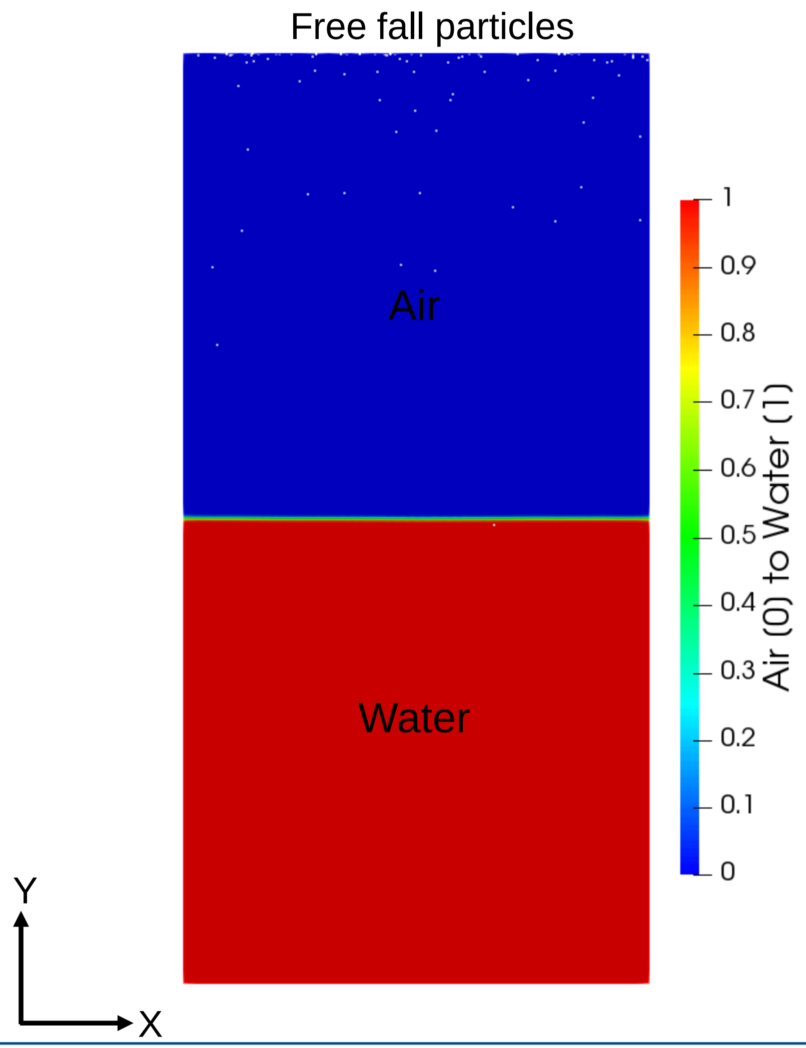
- Tracking the particles by solving the set of ordinary differential equations (Newtonian second law):

$$\frac{dx_P}{dt} = u_P \qquad m_P \frac{du_P}{dt} = \sum F_i \qquad I_P \frac{d\omega_P}{dt} = T$$

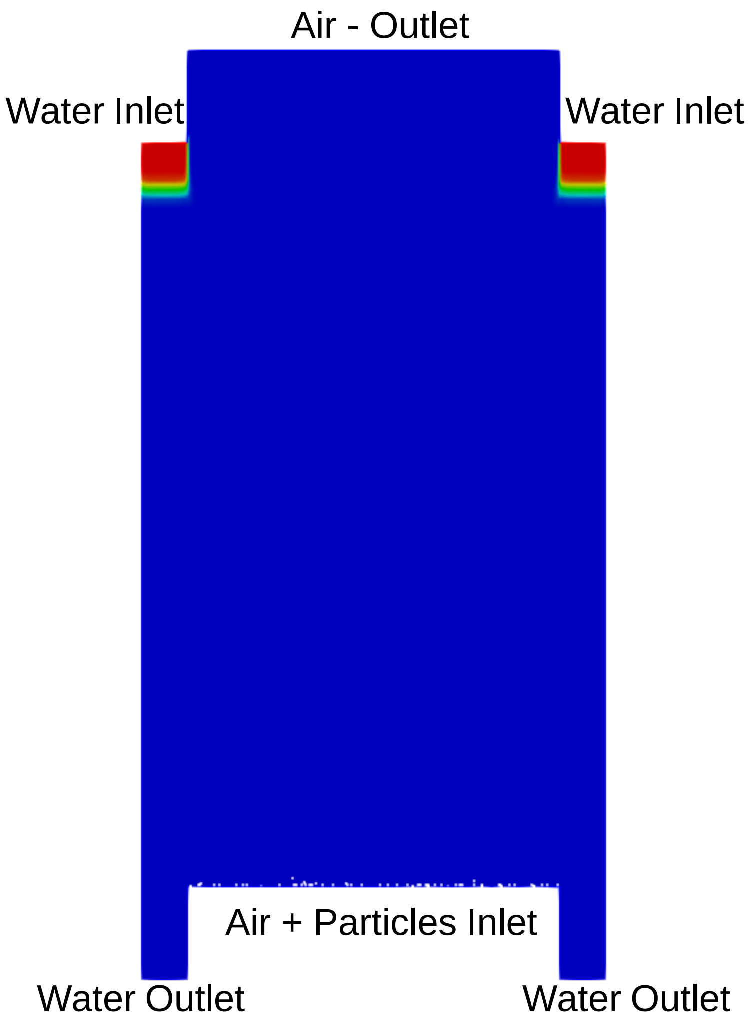
- Surface and body forces:
  - Drag, buoyancy and gravity, thermophoretic, brownian, pressure gradient, lift, saffman …
- Particle-particle and particle-wall contacting forces

MFPI solver tests

Test 1: Computation domain for particle phase transfer from the gas phase into liquid phase

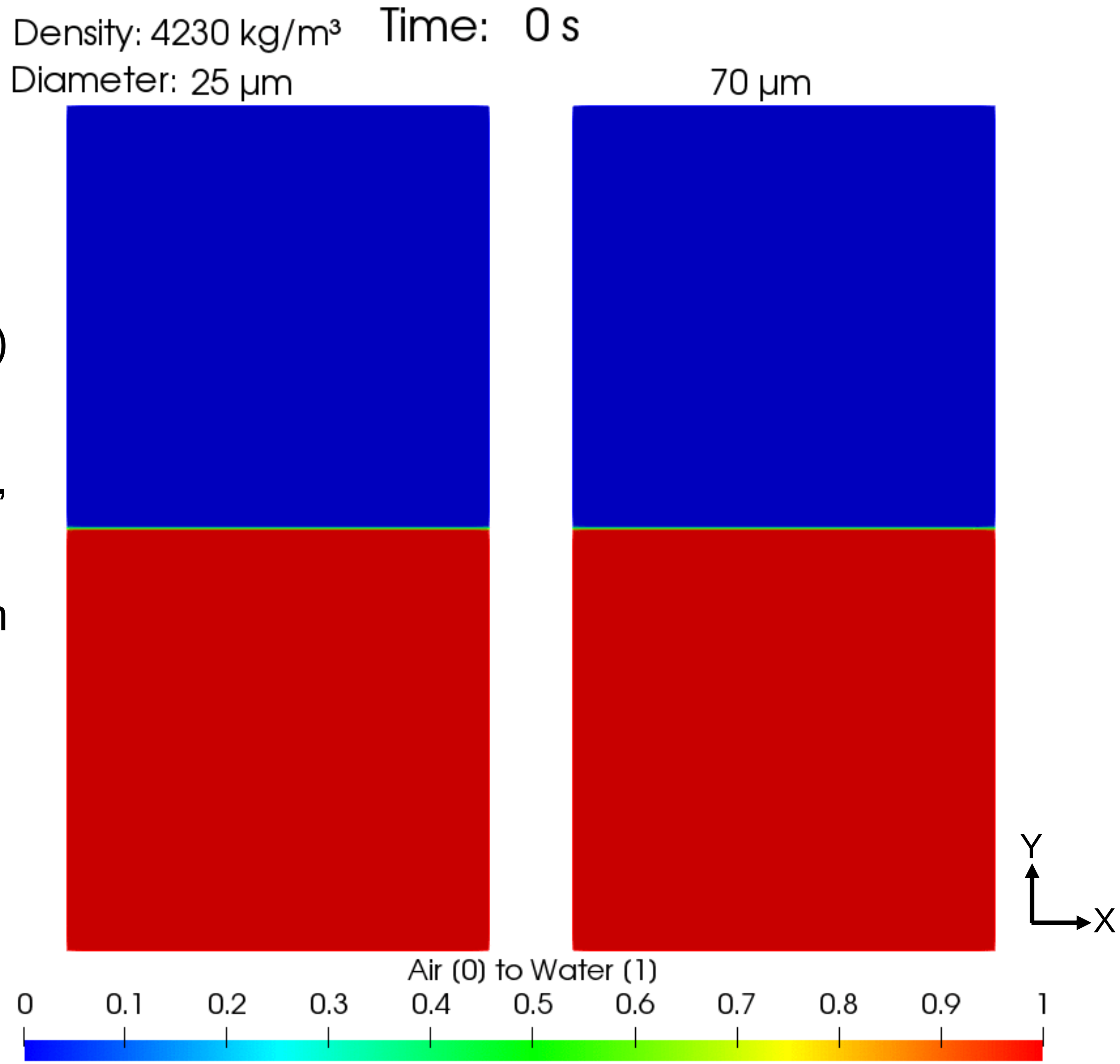


Test 2: Computation domain for the falling film + gas flow with particles



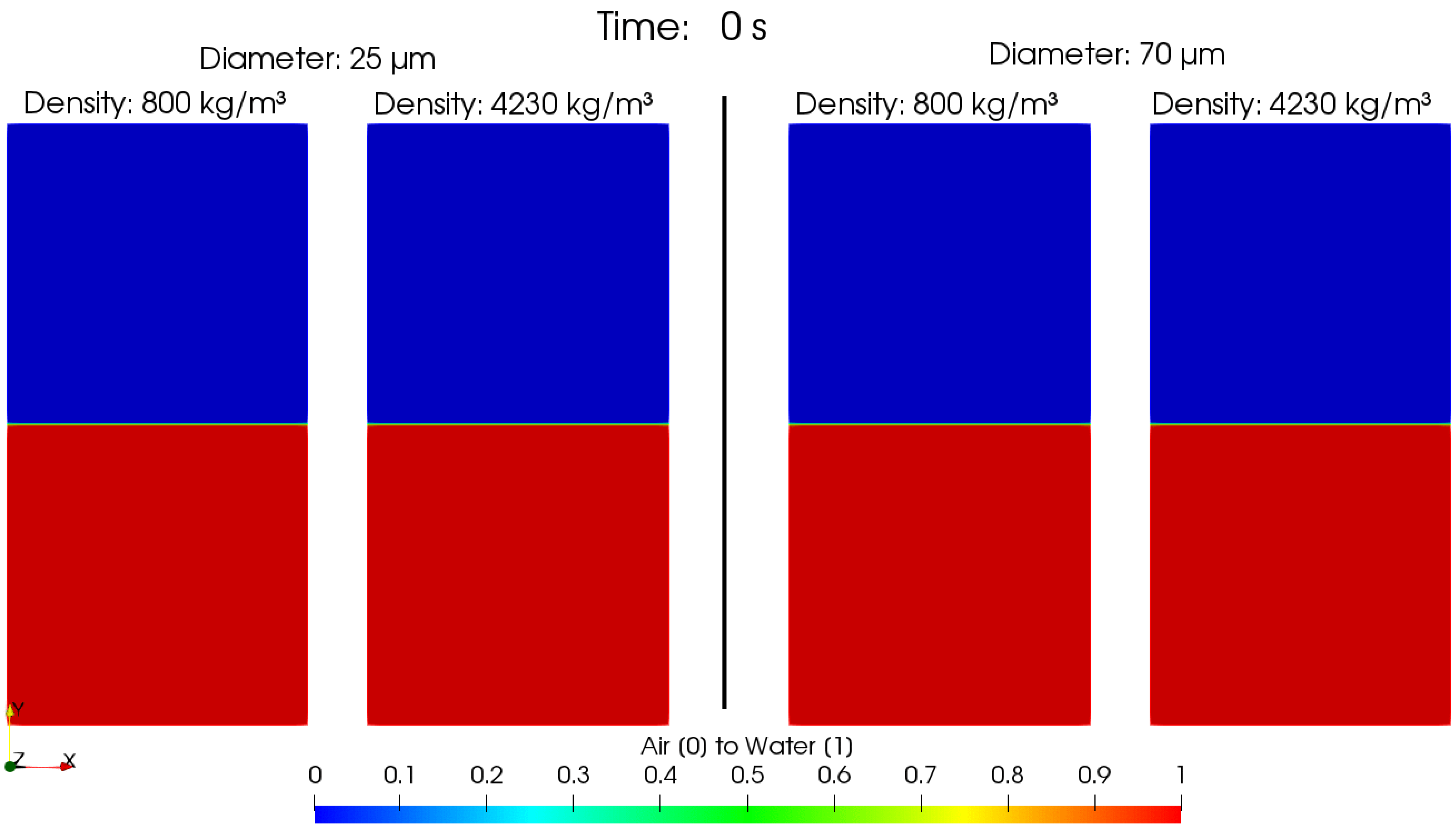
Solver test 1 – Particle phase transfer

- Simulation results for various particle size
- Both fluids (air and water) are at rest
- Surface tension – 0.07 N/m
- Particles are injected into domain (from top patch) with zero initial velocity at 0.05s for 0.2s duration
- Considered forces for particles: Sphere-drag, buoyancy and gravity forces
- Laminar flow simulation and no particle dispersion model



Direct transfer of particles from the gas phase into the liquid phase is possible

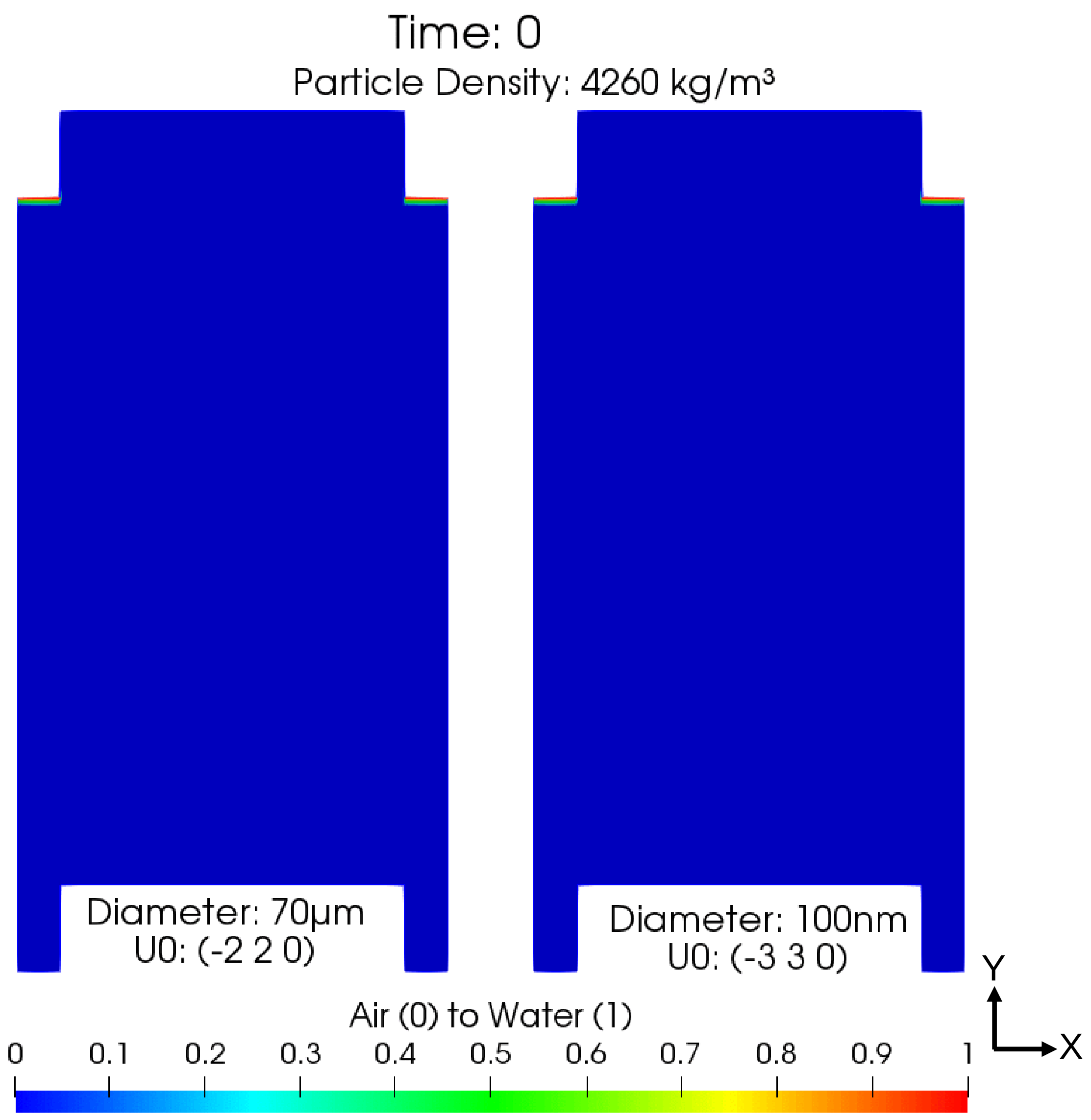
Solver test 1 – Particle phase transfer (additional Info)



Solver test 2 – Falling film + particles

- ❑ Simulation results for various particle size
- ❑ Water flows from top to bottom; whereas Air flows from bottom to top (constant mass flow rate)
- ❑ Surface tension – 0.07 N/m
- ❑ Particles are injected into domain from the Air-Inlet patch with initial velocity U0 in (-1,1,0) direction
- ❑ Considered forces for particles: Sphere-drag, buoyancy and gravity forces
- ❑ Laminar flow simulation and no particle dispersion model

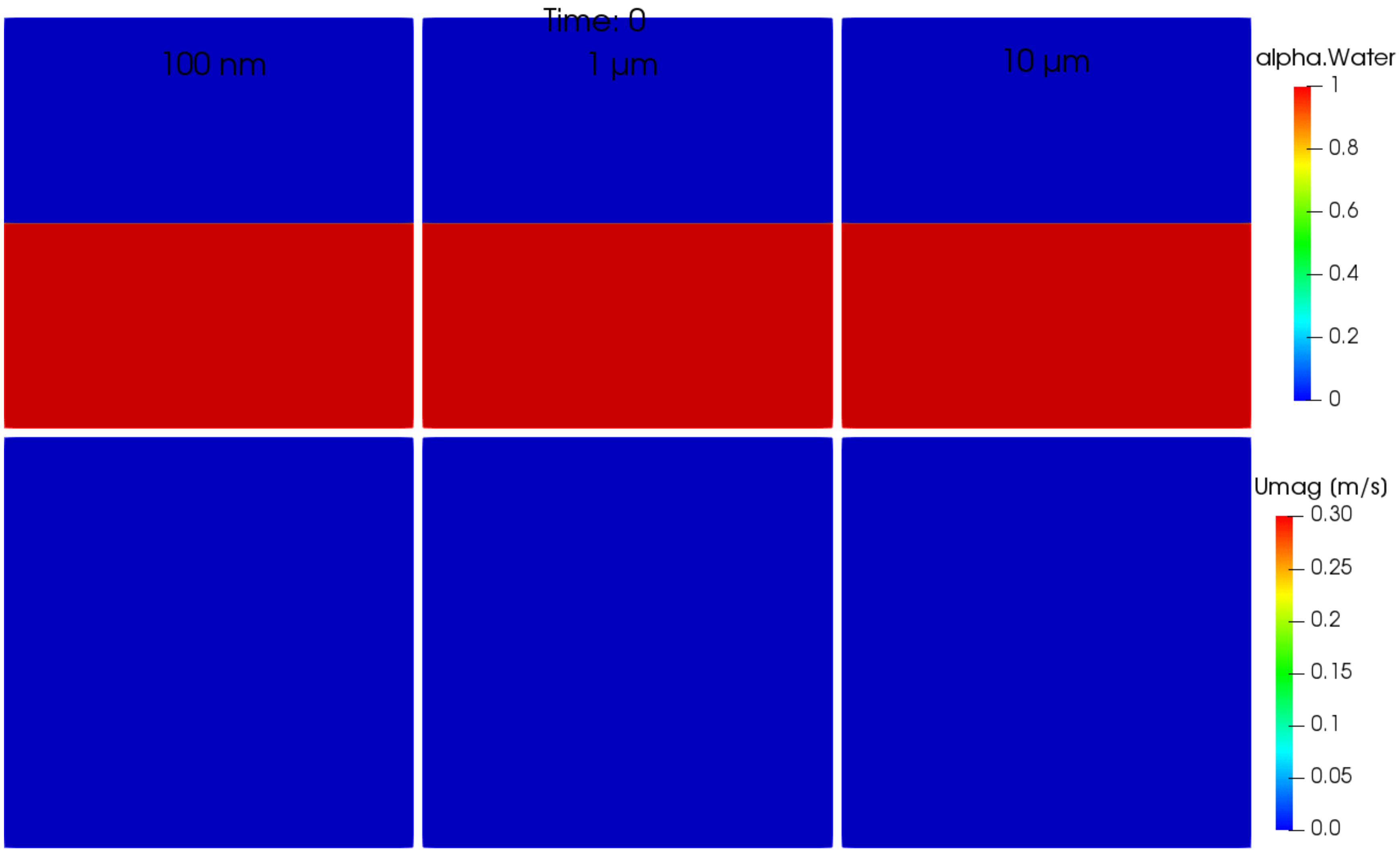
For 100nm particles: Particles are dragged by the gas flow due to the dominated buoyancy force. To drive the particles towards falling film, the electrostatic force is required.



Parametric studies

Finding the required developments to use the model to find the required velocity for particle phase transfer

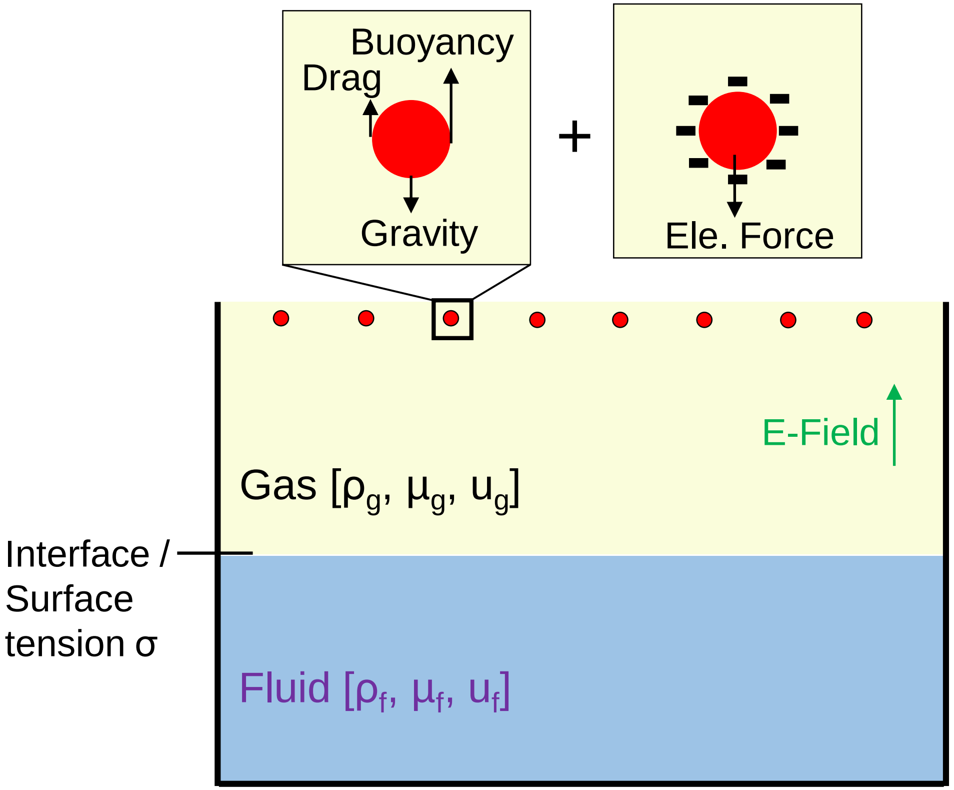
- ❑ Both fluids are at rest
- ❑ Surface tension – 0.07 N/m
- ❑ Particles are injected with initial velocity (0, -0.3, 0)
- ❑ Considered forces for particles: Sphere-drag, buoyancy and gravity forces
- ❑ Laminar flow simulation and no particle dispersion model



Smaller particles: Negligible gravitational settling velocity

Require electrostatic force to drive the smaller particles

Next steps



- ❑ Implement the electrical properties (number of charges, mobility, electric field etc.) as attributes in kinematic cloud class (Data will be imported from EHDM)
- ❑ Implement the electrostatic force calculation model for particles in LPT library
- ❑ Extend the continuum drag model for sub-µm size particles by employing Cunningham corrections
- ❑ Parametric studies with sub-µm size particles to analyse the transmission of particles at gas-liquid interface
- ❑ Simulation with turbulence models for falling film
- ❑ Validation with experimental data

Thank you very much for your kind attention