Vortex Separators

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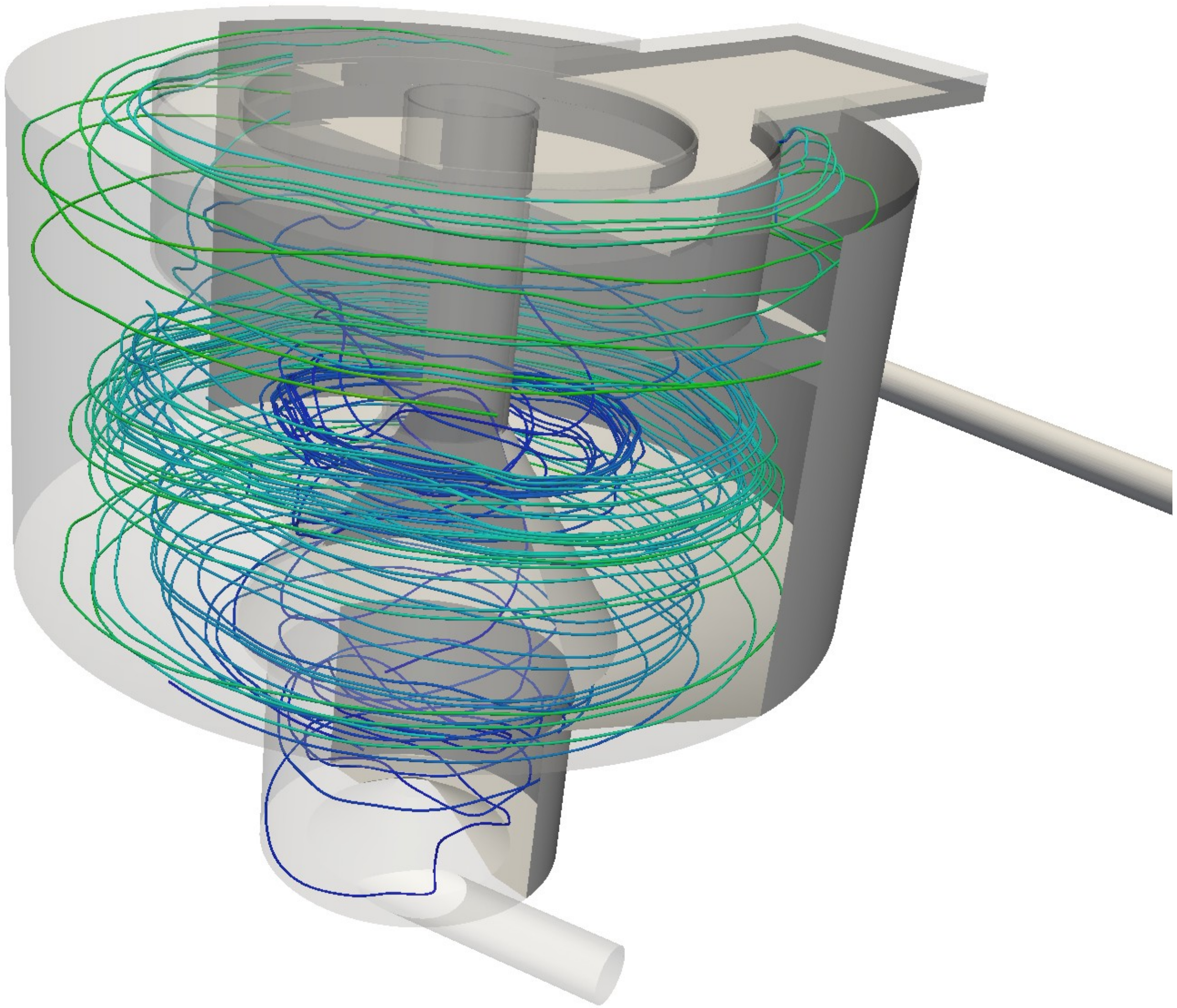
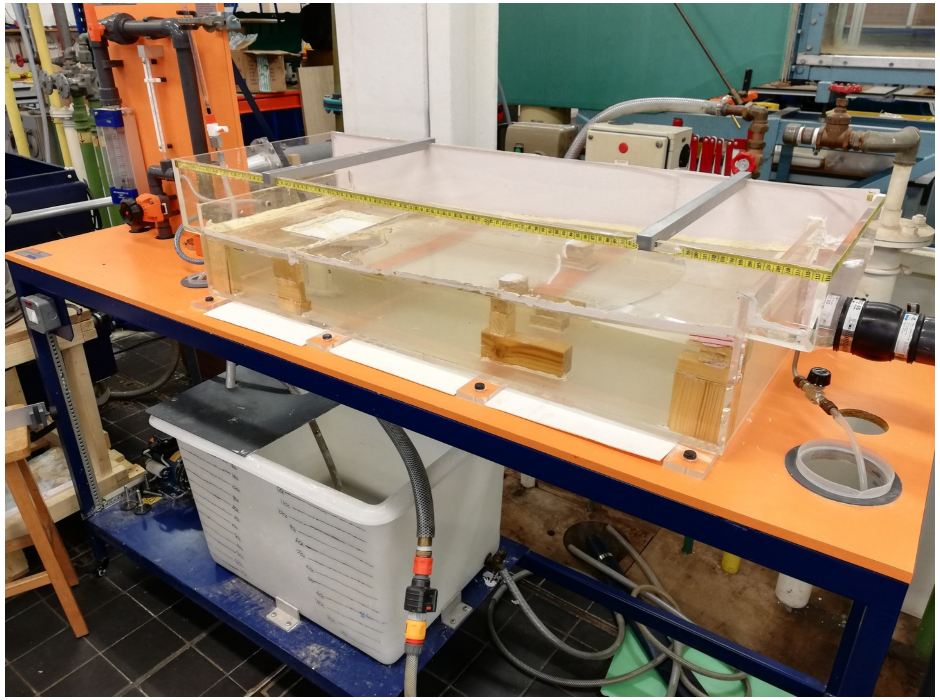
Introduction & Background

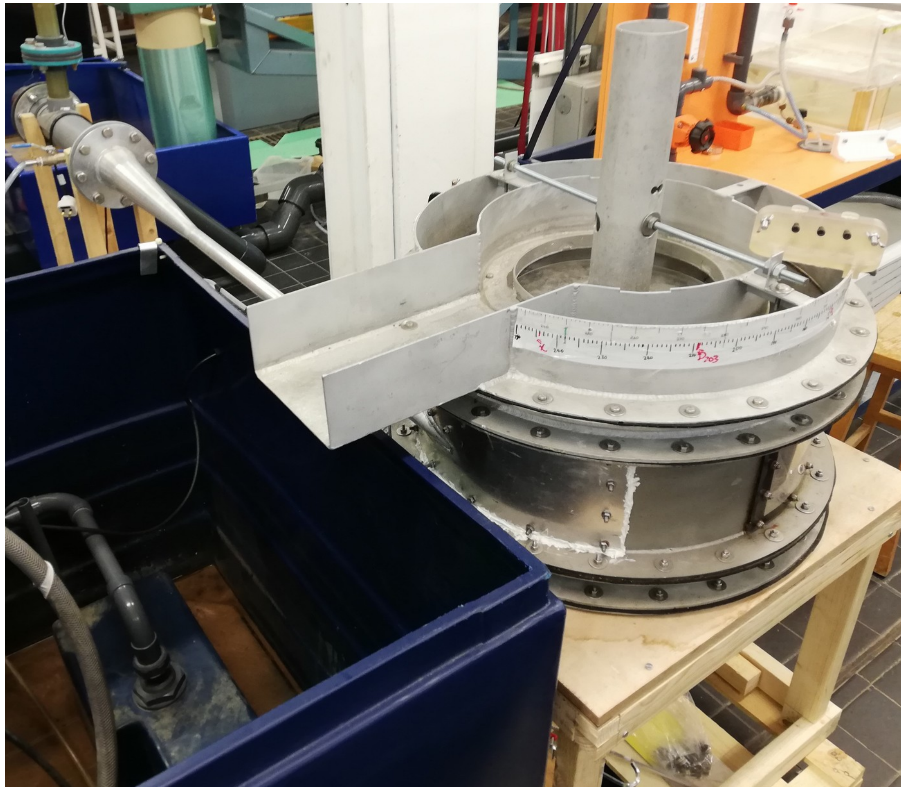
- Wastewater treatment is an ever-present engineering issue.
- Primary treatment uses a variety of gravity driven separators.
- The use of CFD modelling can be used to improve efficiency.
- Olive Stone Powder (OSP) was used as a wastewater substitute.

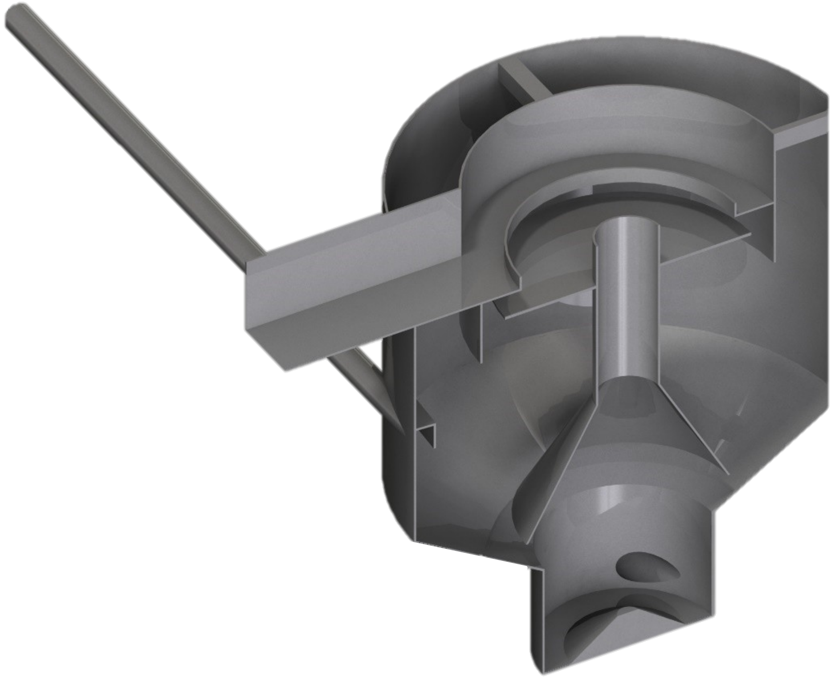


Introduction & Background



Introduction & Background





Key Deliverables

- Mathematical models for both the rheological and settling velocity behaviour.
- CAD geometries of the sedimentation devices with meshed internal domains.
- Comparison of *top-down* and *bottom-up* meshing approaches, documenting quality parameters.
- Empirical studies and 2-phase CFD simulations on both sedimentation devices.
- Comparison of empirical and simulation results to validate the CFD model.
- Investigate design improvements for the Swirl-Flo®.

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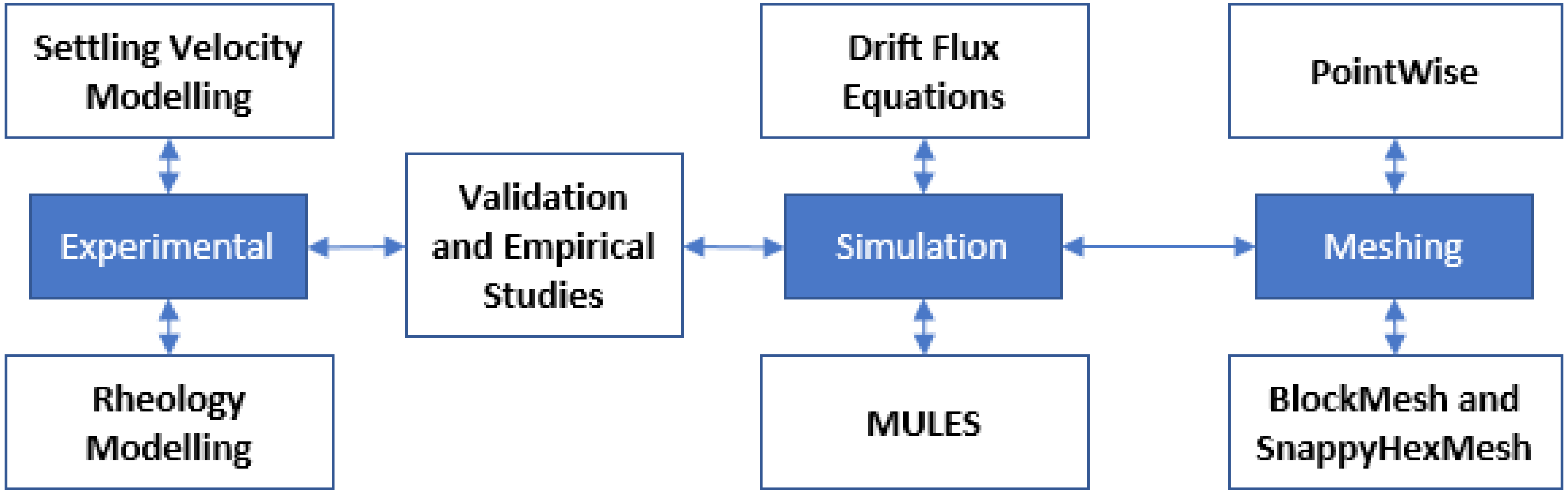
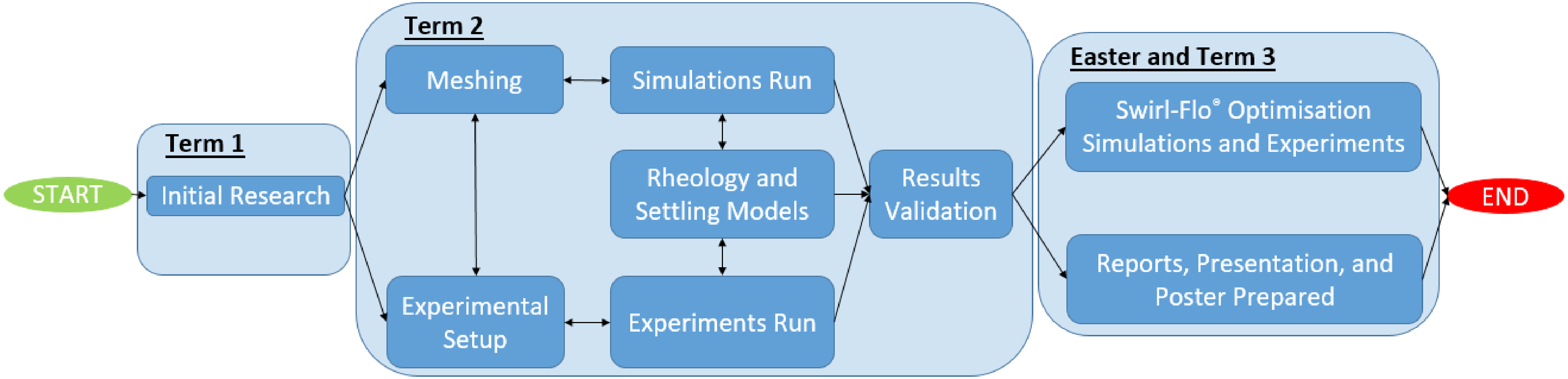
Project Management – Work Packages



Methodology



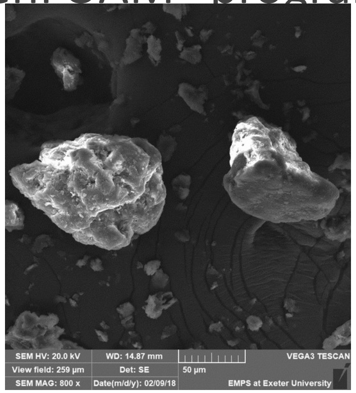
Experimental Sub-Group

Settling Velocity Modelling

- Basis equation
- Swing column
- Settling tubes
- Curve fitting

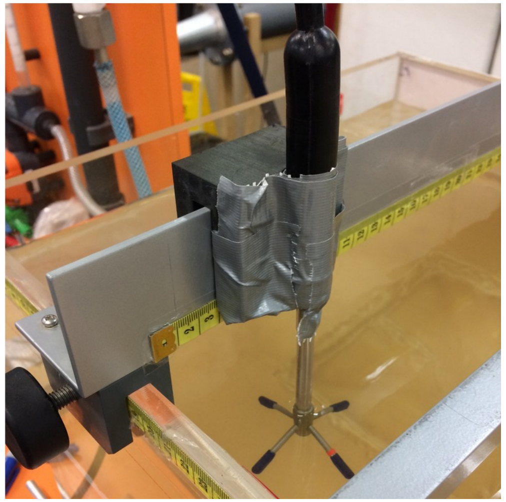
Rheology Modelling

- Sieve shaker
- Microscope imaging
- Random close packing
- Rheometer
- OpenFOAM® programming



Empirical Studies

- Sample concentrations
- Velocity measurements
  - Propeller-meter
  - Acoustic Doppler

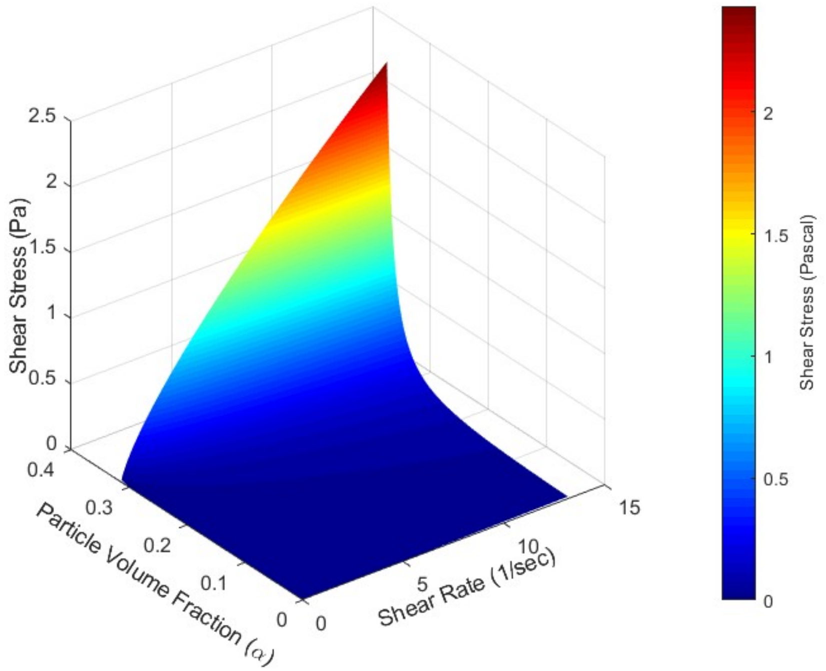


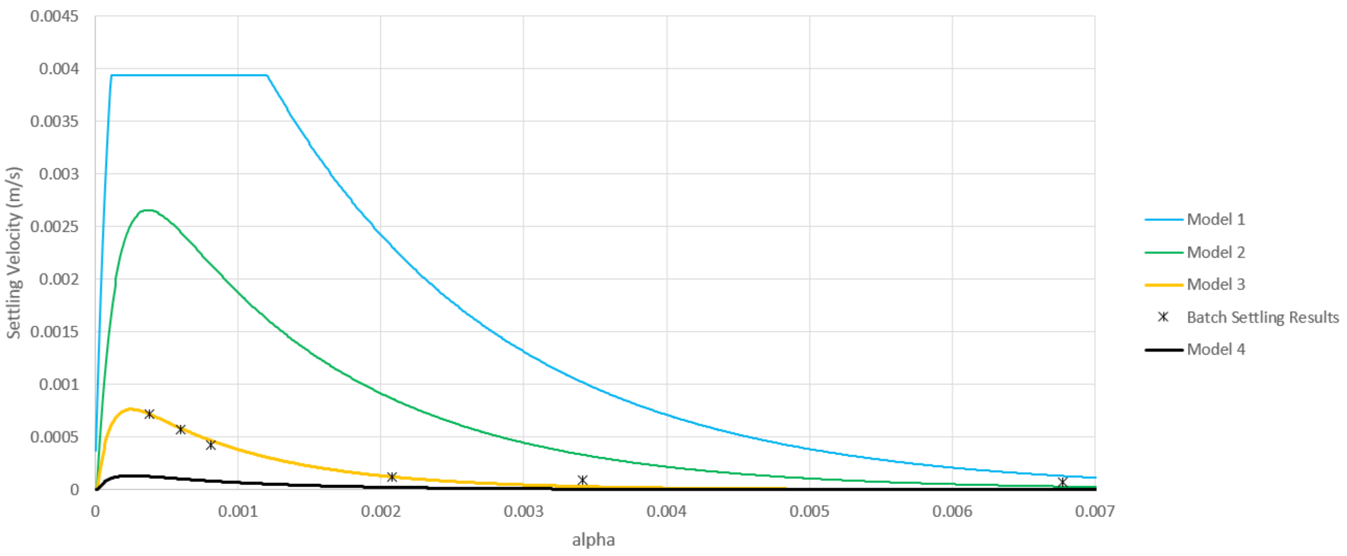
Experimental Sub-Group

- Mathematical models for rheological and settling velocity behaviour.

- Non-Newtonian viscosity model is fairly accurate but is currently computationally non-viable.

- 3 settling velocity models created for the OSP: 2 overestimating, 1 looking promising .

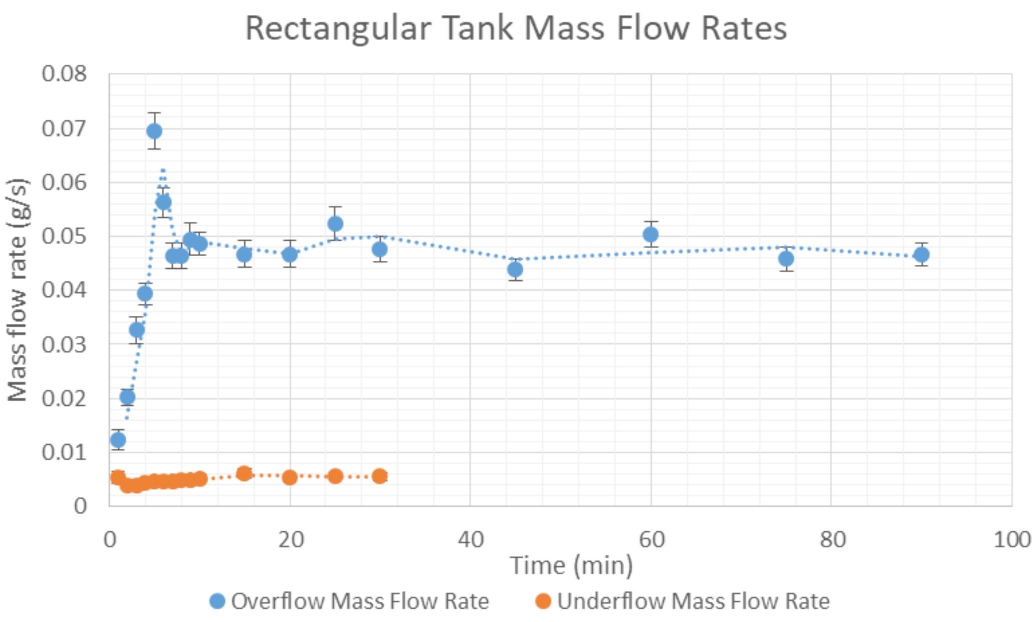


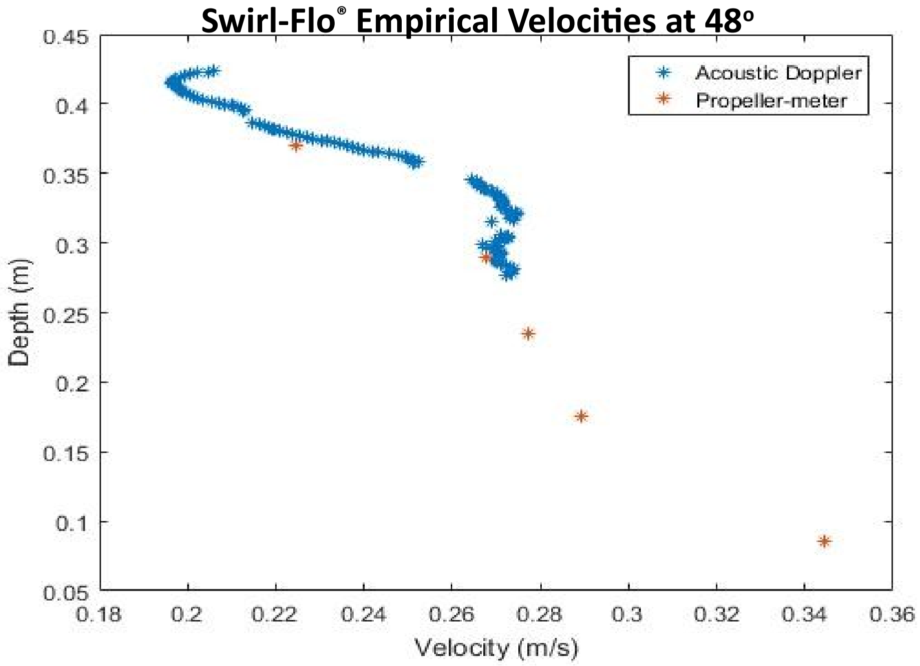


Experimental Sub-Group

- Experiments on the tanks to compare results to the simulations.

- Velocity and mass flow rate results from both tanks.

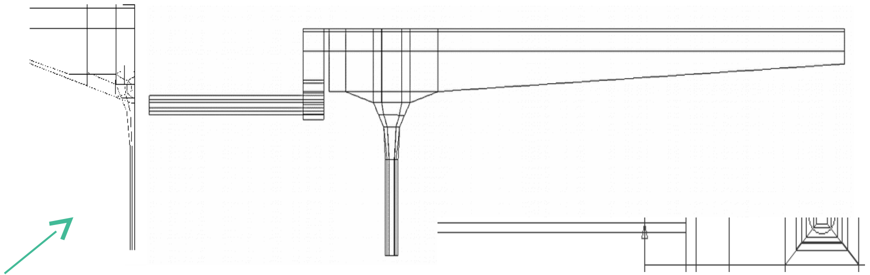


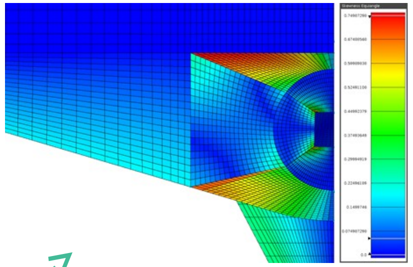


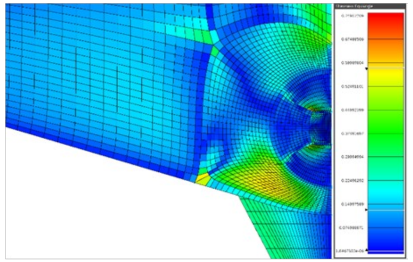
Meshing Sub-Group

Structured Grid Generation

1. Create Geometry
2. CAD Clean-Up
3. Create Grid Plan
4. Implement Scaffold
5. Create Multi-Block Mesh
6. Smooth using Eliptic Solver



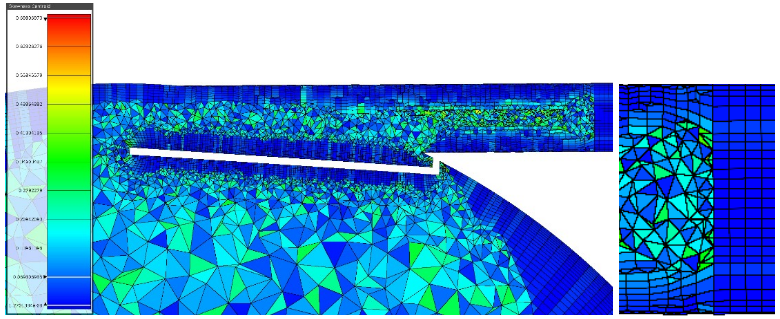


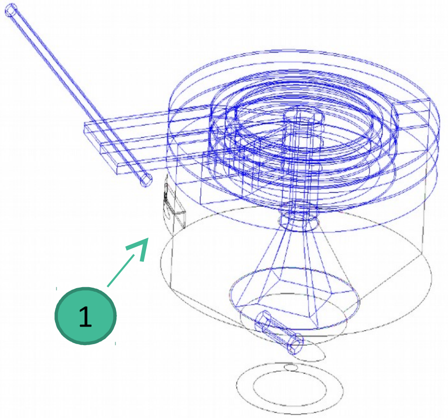


Hybrid Grid Generation

- Create Geometry
- CAD Clean-Up
- Regular Geometry?
  - Create Structured Grid Plan → Implement Scaffold → Create Multi-Block Mesh → Smooth using Eliptic Solver
  - Create Unstructured Block → Initialise With T-Rex Boundary Layers → Max Centroid Skewness below 0.7? → Final Mesh
    - Change T-Rex Parameters → Initialise With T-Rex Boundary Layers

1





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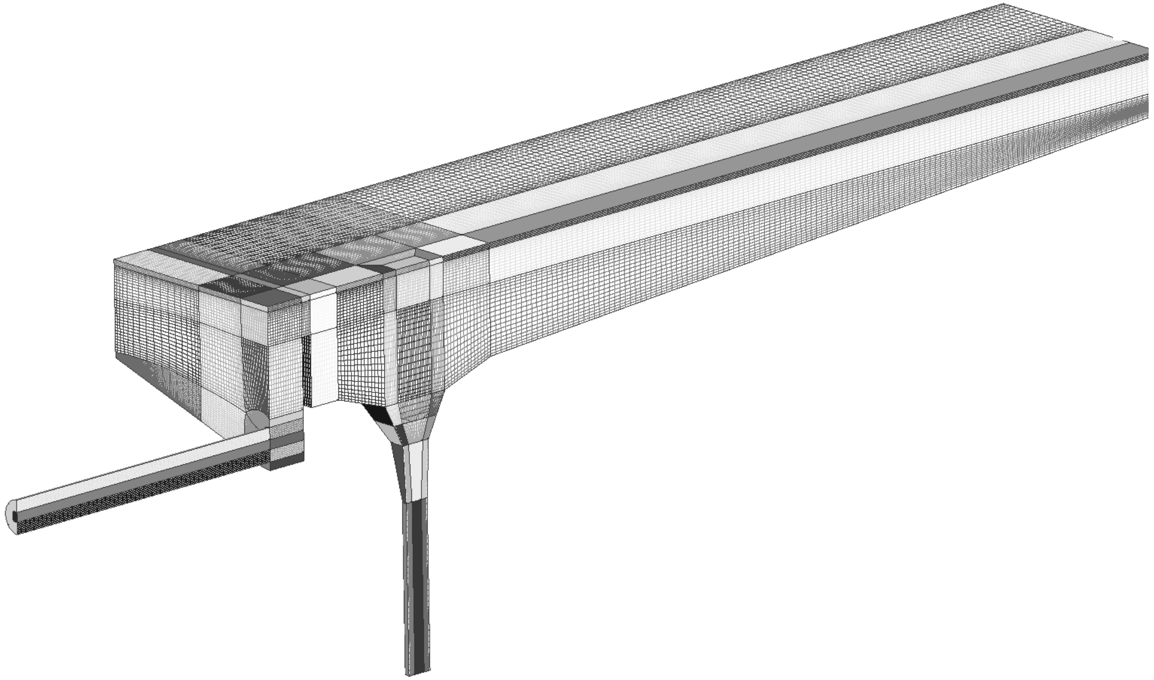
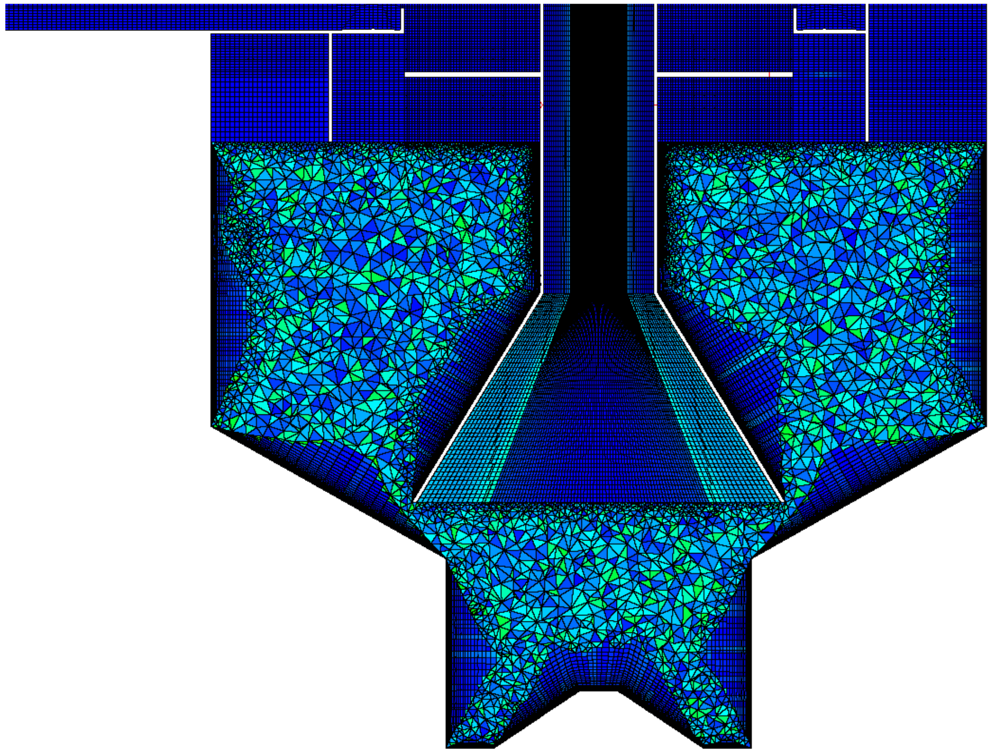
Meshing Sub-Group

Structured Rectangular Settling Tank

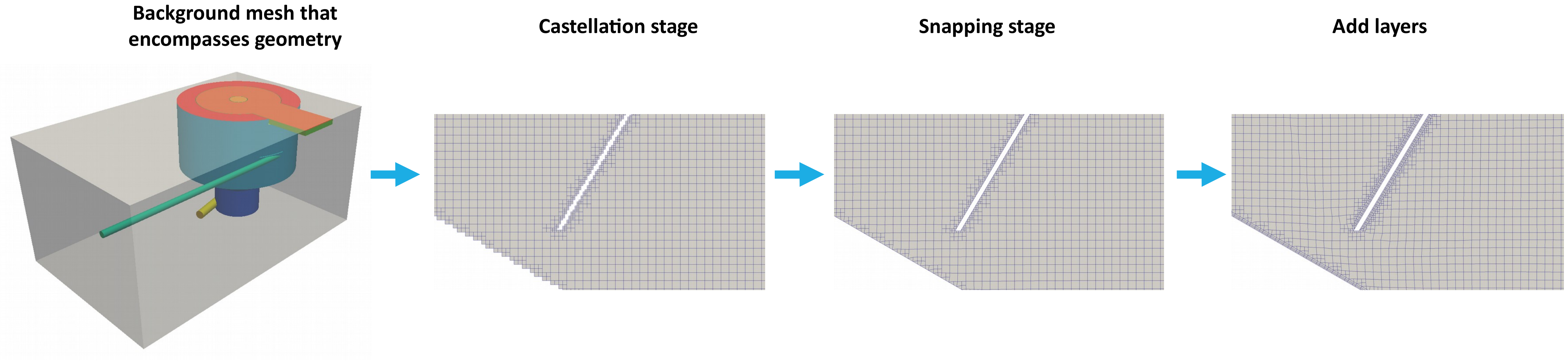


Hybrid Swirl-Flo®



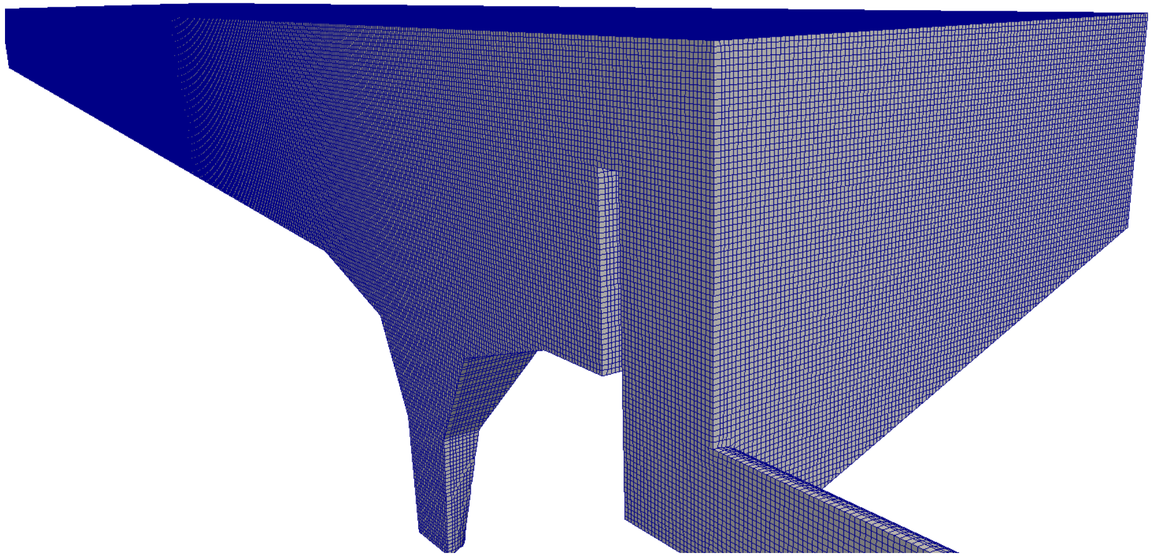
Meshing Sub-Group

- `snappyHexMesh` is a native OpenFOAM® meshing utility.
- Creates hex-dominant meshes.
- Controlled using a C++ dictionary (no graphical user interface).

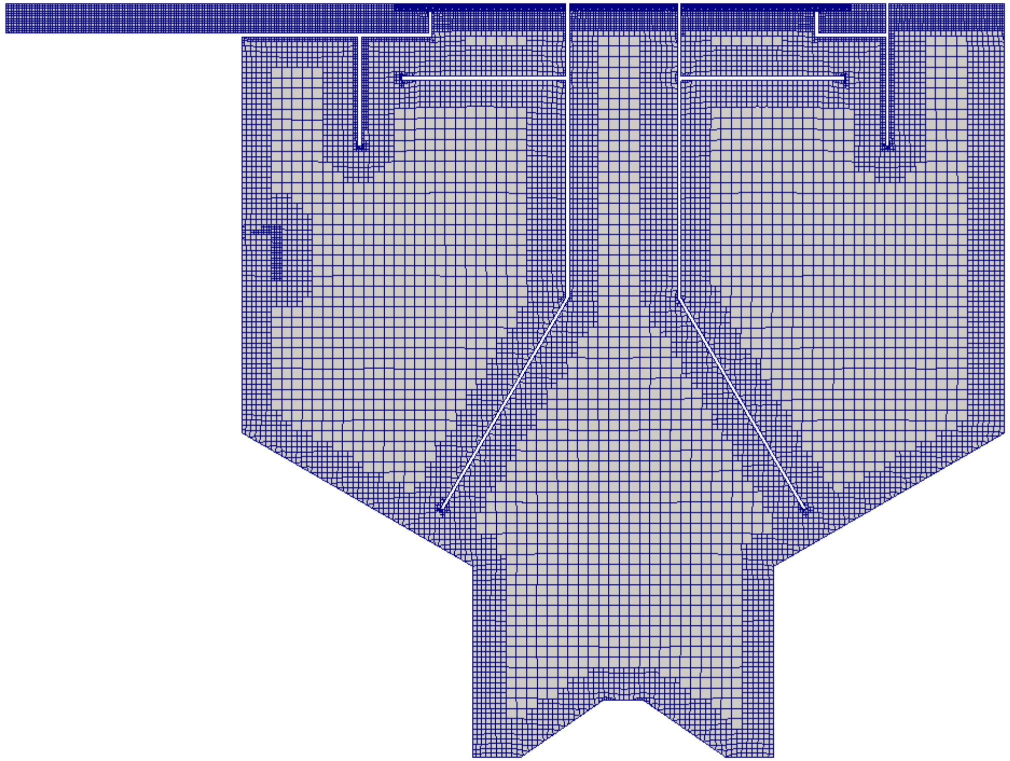


Meshing Sub-Group

Rectangular Settling Tank



Swirl-Flo®



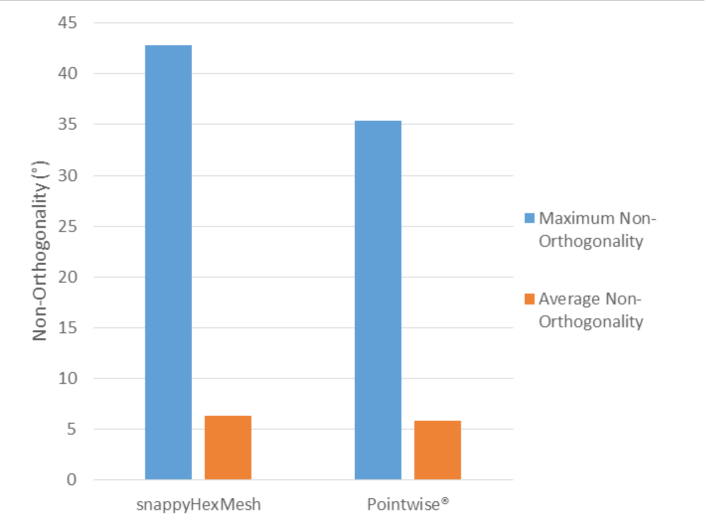
Meshing Sub-Group

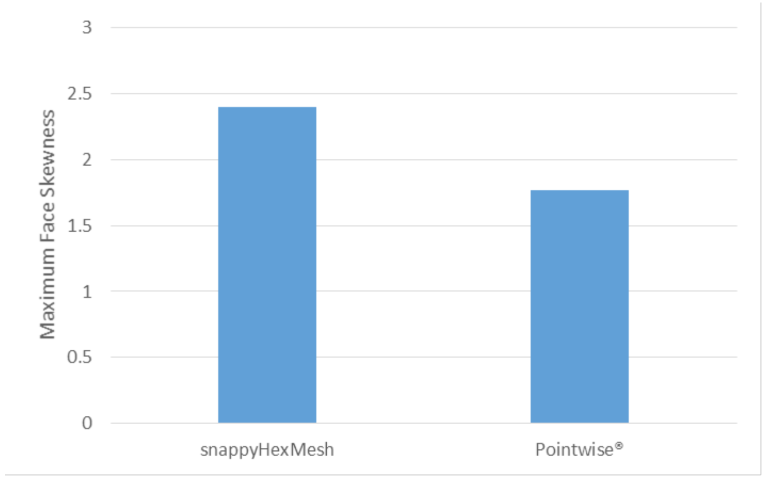
- `snappyHexMesh` can quickly generate grids but has poor boundary layer control.

- Pointwise® mesh generation is more time consuming but has good boundary layer control.

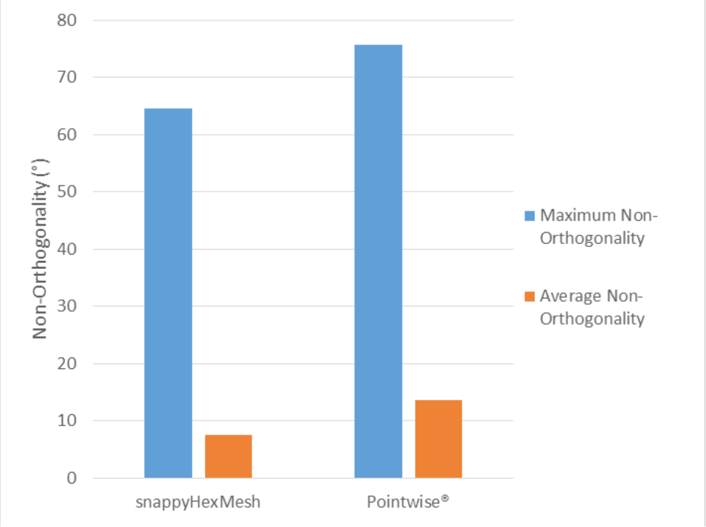
- Graphs show selection of mesh quality metrics.

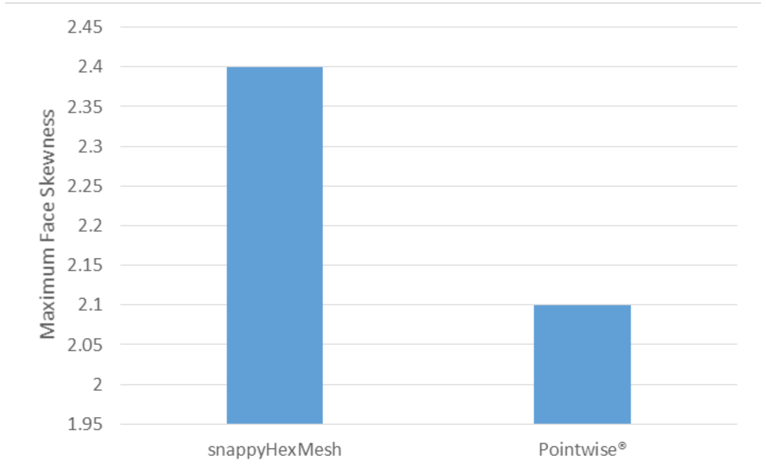
Rectangular Tank





Swirl-Flo®





Simulation Sub-Group

- Aimed to produce accurate efficient simulations using `driftFluxFoam` in OpenFOAM®.

- Research into Multiphase Modelling – Drift Flux equations and MULES.

- Equations are discretised into the computational domain.

Mixture Continuity Equation:

$$\frac{\delta \rho_m}{\delta t} + \boldsymbol{\nabla} \cdot (\rho_m \nu_m) = 0$$

Mixture Momentum Equation:

$$\frac{\delta \rho_m \nu_m}{\delta_t} + \boldsymbol{\nabla} \cdot (\rho_m \nu_m \nu_m) = -\boldsymbol{\nabla} \cdot P_m + \boldsymbol{\nabla} \cdot \boxed{[\tau + \tau^t]} + \boldsymbol{\nabla} \cdot \left(\frac{\alpha_d}{1 - \alpha_d} \frac{\rho_c \rho_d}{\rho_m} \boxed{\nu_{dj} \nu_{dj}} \right) + \rho_m g + M_m$$

Dispersed Phase Continuity (Diffusion) Equation:

$$\frac{\delta \alpha_d}{\delta t} + \boldsymbol{\nabla} \cdot (\alpha_d \nu_m) = -\boldsymbol{\nabla} \cdot \left(\frac{\alpha_d \rho_c}{\rho_m} \boxed{\nu_{dj}} \right) + \boldsymbol{\nabla} \cdot \Gamma \nabla \alpha_d$$

Simulation Sub-Group

- Models were run for between 600 and 1100 simulated seconds.

- Quasi-steady state behavior was observed after 400-500 seconds.

- The vast majority of OSP falls through the hopper.

- Maximum value for phase fraction was over quadruple the initial phase fraction.

- The difference in results for the models indicated OSP is not a good substitute for sludge.

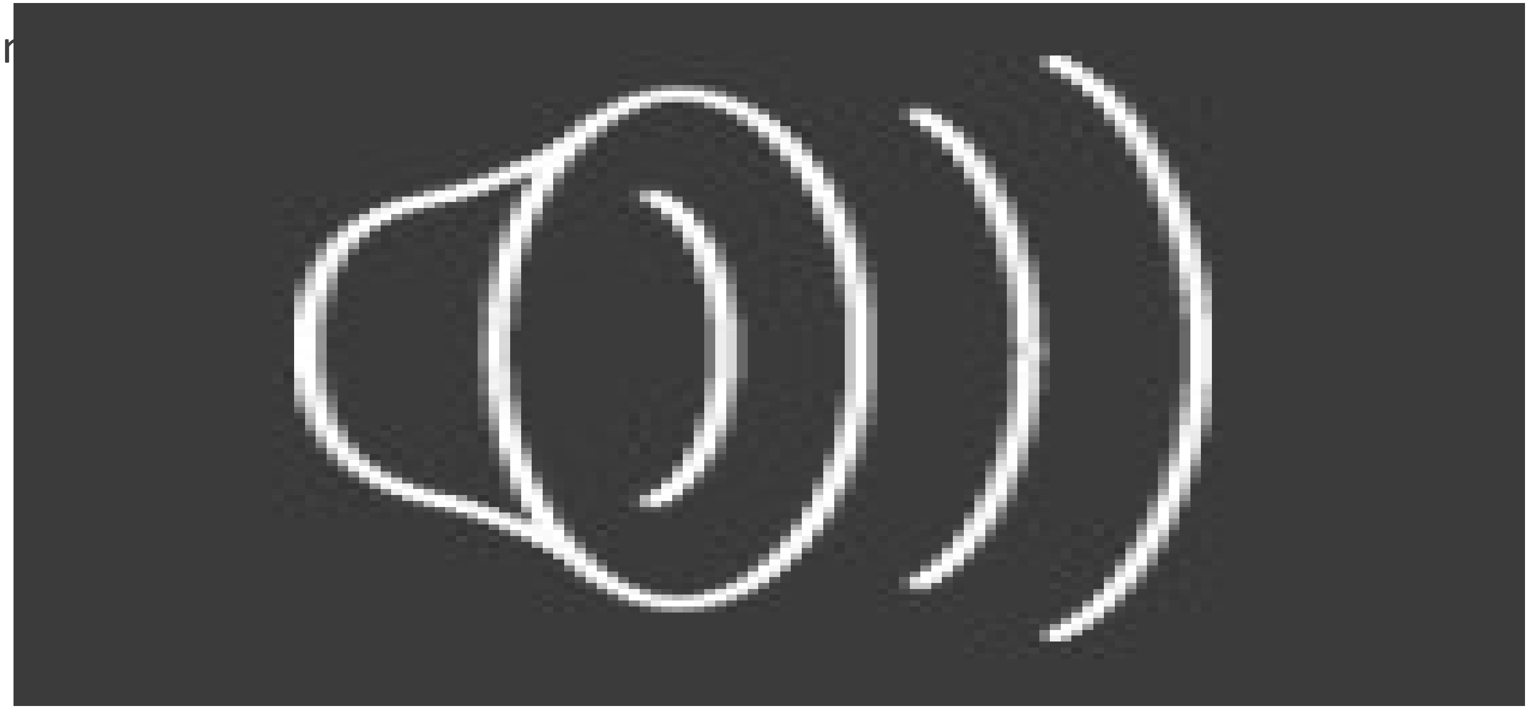
Simulation Sub-Group

- Simulations reached only 130 simulated seconds after 19 days on a simple, non-turbulent model.

- Quasi-steady state behavior was not achieved.

- Similar trends were present; running for longer could show more similar results and model validation.

- Non-Newtonian viscosity model would take 27 years to reach 5 simulated minutes on available architecture.

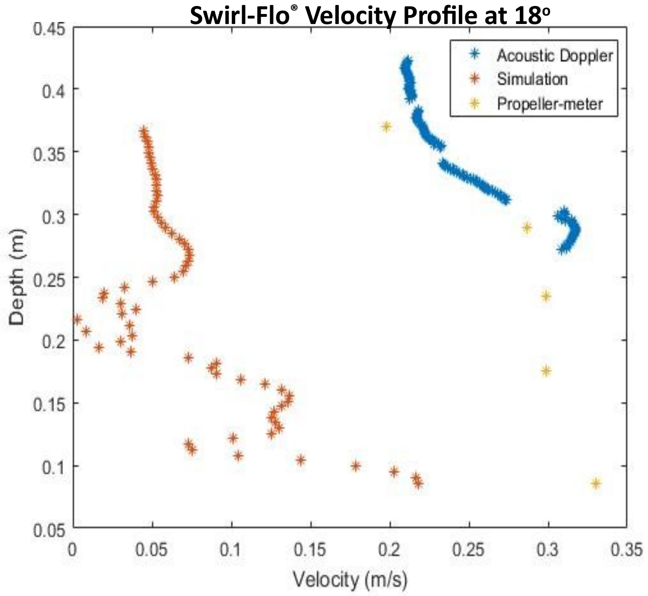


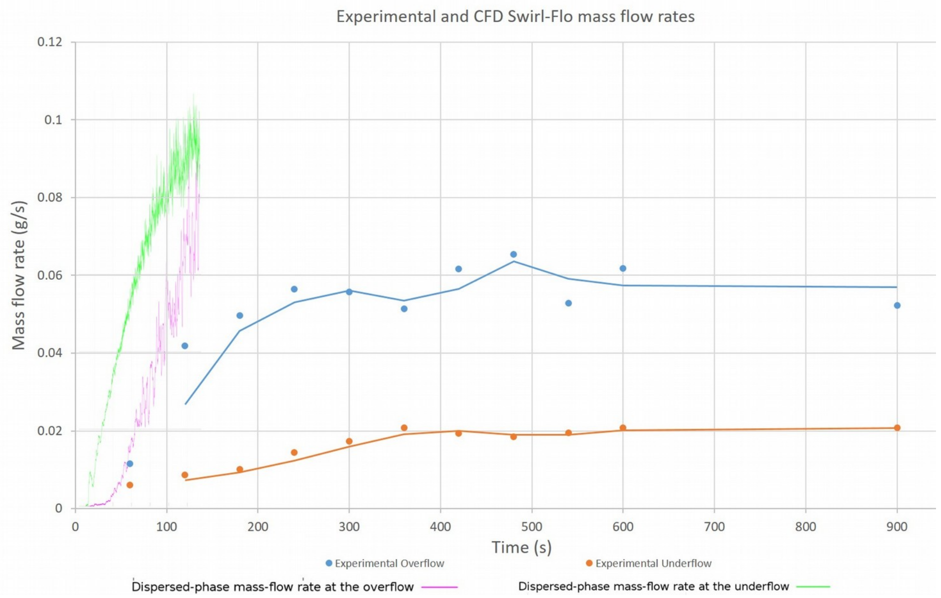
Validation Results

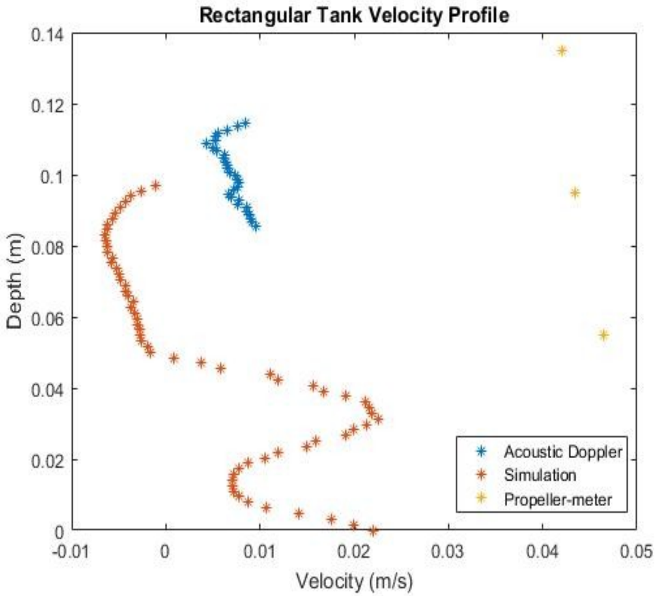
- Velocity Profiles:
  - Large difference between magnitudes.
  - Similar trends regarding velocity and depth.

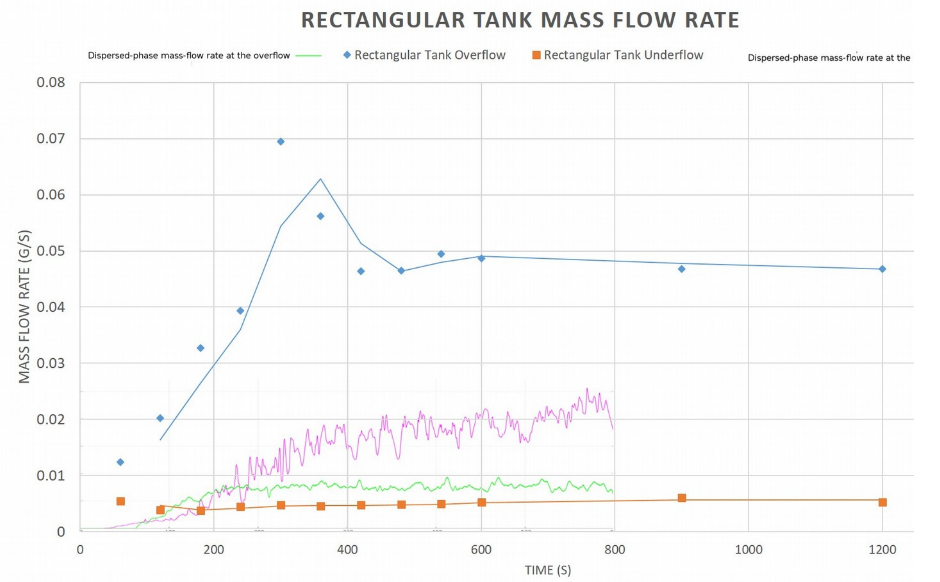
- Mass Flow Rates:
  - Large differences between magnitudes.
  - Same convergence times for rectangular tank.

- Simulations are not validated due to magnitude differences.









Conclusions

- Model 4 settling model is looking promising. Most accurate viscosity model is not computationally viable, but an appropriate model was found.

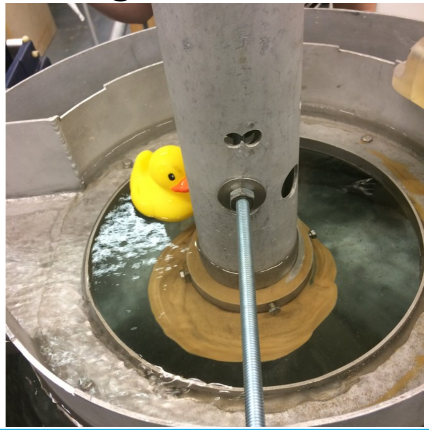
- Accurate CAD geometries were created.

- `snappyHexMesh` can generate meshes quickly but has poor boundary layer control. Pointwise has greater control over boundary layers but has non-orthogonality issues with `driftFluxFoam`.

- Experiments were completed with full results found. Simulations were finished on rectangular, unable to fully complete on Swirl-Flo® due to computational time limitations.

- Validation inconclusive, however, similar trends were observed.

- Optimisation stage was not reached due to computational time limitations.



Any questions?