Enabling Industrially Relevant DEM-SPH Simulations With Rocky

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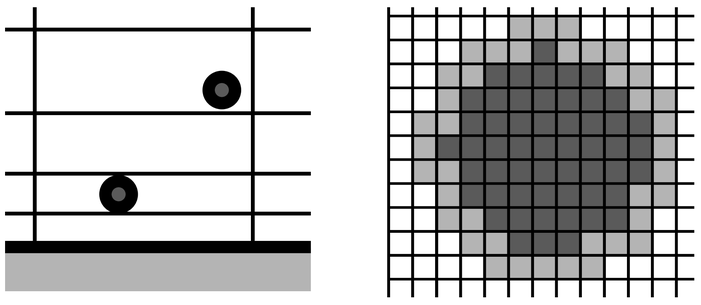
Motivation

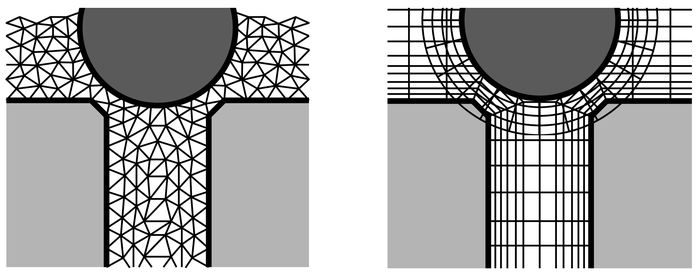
The coupling of solid bodies with CFD solutions shows some limitations regarding object size, small gaps and mesh deformations.

Unresolved CFD-DEM $D_P \leq L_C^{\min}$ **Semi-resolved CFD-DEM** $D_P \geq 10 * L_C^{max}$



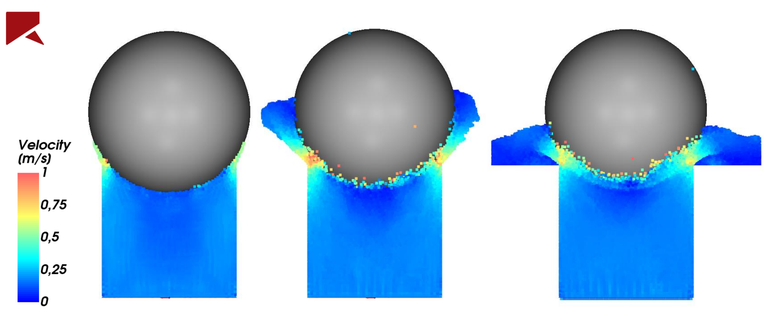
Particle coupling approaches for small objects

Remeshing **Overset mesh**



Moving boundary approaches for large objects

From the numerical point of view, the approaches above suffer from instability when solid fractions in single cells approach 1 or when gaps between boundaries are closing. This is a result of the implicit solution inside the FV codes which needs special treatment if necessary.

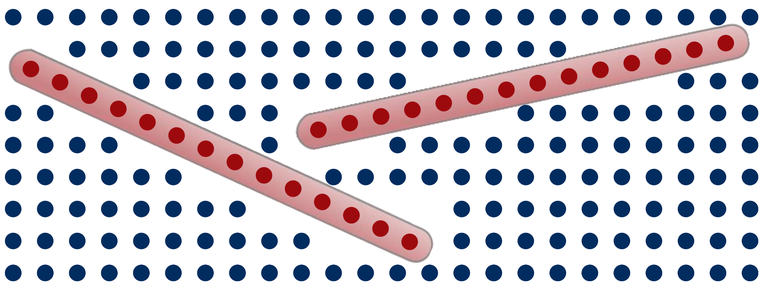


Opening ball valve with SPH-DEM approach

With a particle-based approach to model the fluid via SPH elements, the size restrictions can be loosened greatly, and small gaps or high solid volume fractions can be covered, based on the common explicit approach of SPH and DEM.

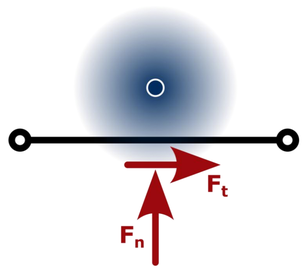
Methodology

For the direct coupling of DEM and SPH, the DEM particles are resolved by SPH elements [1] which positioning can be background grid or DEM conformal. Both approaches offer advantages and disadvantages.



DEM conformal resolution of DEM particles by SPH elements

The second part is the coupling of SPH and the boundaries. It has been found that the most efficient approach is to use triangulated geometries, just like for DEM. This approach allows an explicit distinction between normal and tangential forces, as well as a common description of the boundaries with variable resolution, saving memory and computational time. The force on the SPH elements near the boundaries is determined based on their distance from the wall triangles, as well as their relative speed.

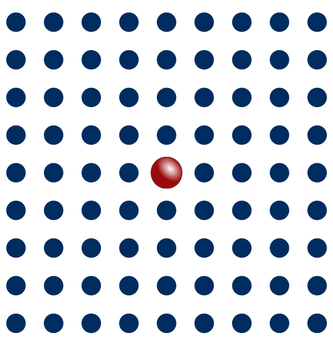


$$F_n = K_n(0.5h - d) + K_d v_n$$

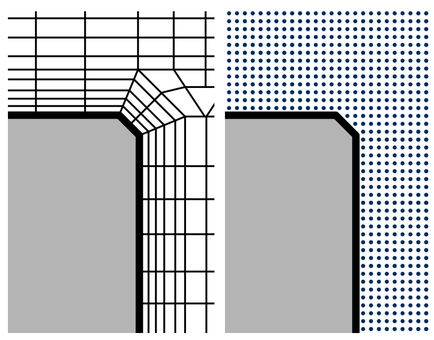
$$\boldsymbol{F}_t = \frac{\mu d_{ini}^2 \boldsymbol{v}_t}{d}$$

Model Limitations

The current approach of DEM-SPH coupling still has some limitations: DEM particles must be larger or equal to the SPH element size. The SPH elements offer no variable resolution, and the simulation only covers one phase of SPH elements.



$D_P > D_{SPH}$



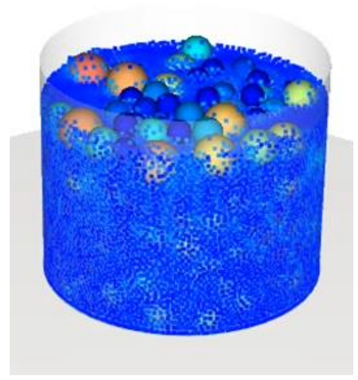
variable resolution in CFD (left) and constant resolution of SPH (right)

Rocky DEM-SPH Features

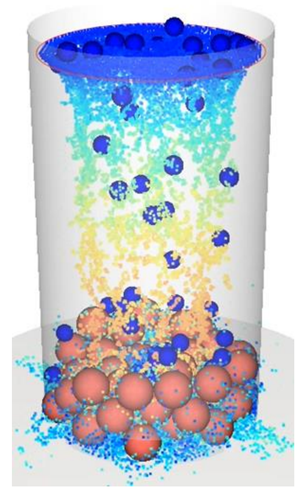
With SPH implemented in Rocky, the underlying framework offers several usable functionalities:

Inlet conditions

Combined inlet conditions for SPH and DEM (volume fill and inflow) allowing for continuous inflow of liquid and solid supporting accurate mass flow and particle size distributions



Combined volume filling

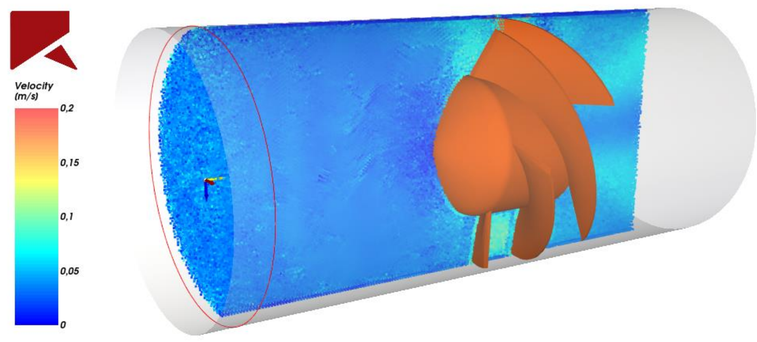


Combined inflow condition

Motion frames

All motion frames inside Rocky are compatible with the SPH solver, containing:

- Force- & displacement-controlled motion
- Periodic motion (vibration & oscillation)
- Combined motion frames (nested motions)



Multi-GPU performance

The Rocky solver allows for up to 8 GPUs solving one problem handling DEM and SPH in an optimized manner.

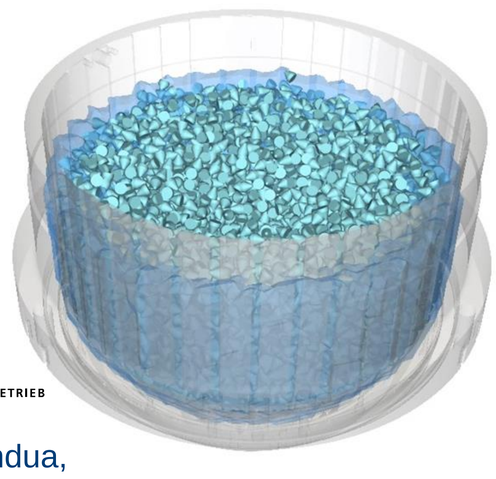
API (Programming Interface)

Rocky offers an API which allows to manipulate every physical part of the underlying SPH computations while offering an automatic parallelization on CPU and GPU.

Applications

Wet grinding

- Depicting the influence of process water
- Calculate grinding work and mixing



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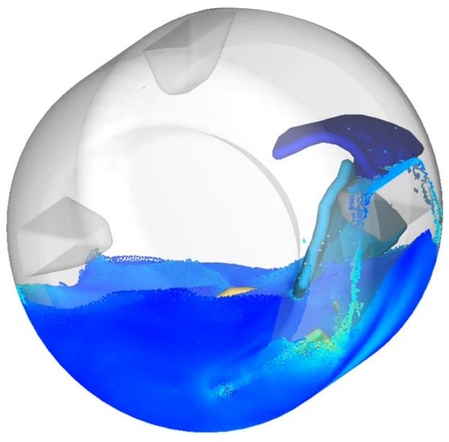
Courtesy of F. Landua, Y. Kuche, Fraunhofer IPK

Home Appliances

- Many areas where water and solids mix (kitchen equipment, washing machines, toilets)
- Flexible solids of all shapes can be covered

Washing machine simulation with flexible shells modeling clothes

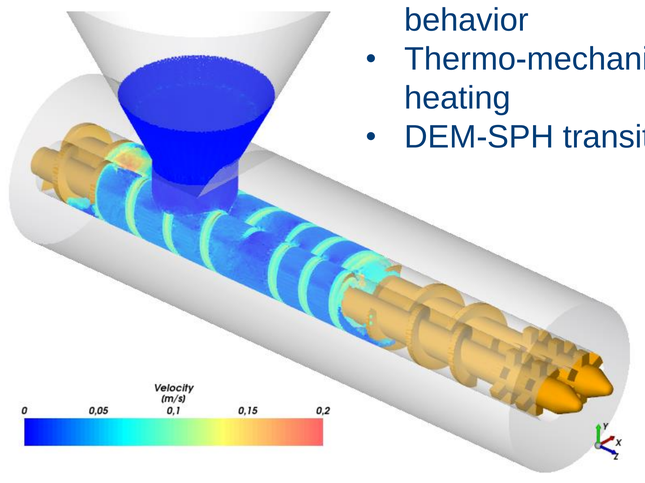


Plastic extrusion

- Undercutting geometries
- Visco-elastic materials
- Thermo-mechanics

Future steps:

- Non-Newtonian behavior
- Thermo-mechanical heating
- DEM-SPH transition



[1] A. V. Potapov, M. L. H. and Campbell, C. S. (2001). Liquid–solid flows using smoothed particle hydrodynamics and the discrete element method. Powder Technology, 116:204 – 213