A New Boundary Treatment for Complex Geometries in Smoothed Particle Hydrodynamics

A. Eitzlmayr1, S. Ral1, C. Kloss2,3, G. Koscher4, J. Khinast1,4

1 Graz University of Technology, Institute for Process- and Particle Engineering, Graz, Austria
2 Johannes Kepler University Linz, Christian-Doppler Laboratory on Particulate Flow Modelling, Linz, Austria
3 DCS Computing GmbH, Linz, Austria
4 Research Center Pharmaceutical Engineering GmbH, Graz, Austria

Contact: khinast@tugraz.at

I. INTRODUCTION

- Boundary methods for Smoothed Particle Hydrodynamics (SPH) are typically based on particles [1] (e.g., boundary particles, ghost particles).
- For complex geometries encountered in industrial applications, the use of boundary or ghost particles is problematic [2].
- We developed a new method which uses continuous walls (e.g., in the STL format) instead of particles.
- Our implementation is based on “LIGGGHTS”.

II. BOUNDARY PARTICLE CONTRIBUTIONS

Isolation of the boundary particle contributions from the SPH continuity and momentum equation:

\[ \frac{d\rho}{dt} = \sum \frac{\mathbf{F}_{\text{inter}}}{\rho} - \sum \frac{\mathbf{F}_{\text{wall}}}{\rho} \]

\[ \frac{d\mathbf{v}_i}{dt} = \frac{1}{\rho_i} \left( \sum \frac{\mathbf{F}_{\text{inter}}}{\rho_i} - \sum \frac{\mathbf{F}_{\text{wall}}}{\rho_i} \right) \]

Numerical determination of dim.-less boundary contributions:

- **Fixed wall distance z**
  - constant velocity
  - fluid particle
  - boundary particle

Fitted polynomials:

\[ F_{\text{wall}}(z) = -0.607 \cdot z^5 + 2.59 \cdot z^4 - 3.09 \cdot z^3 - 0.059 \cdot z^2 + 0.37 \]

(Re = 0.12, Re = 0.4)

\[ F_{\text{wall}}(z) = 0 \]

(Re = 1.43, Re = 0.4)

III. ENFORCEMENT OF NO-SLIP CONDITION

Position of continuous wall vs. boundary particles and corresponding tangential velocity profiles:

- **B.P.:**
  - wall fluid
  - wall fluid

- **Continuous wall (STL):**
  - no wall slip, but empty layer at the wall
  - completely filled, but wall slip
  - completely filled, no wall slip

IV. WALL REPULSION

Power p = 4 [4]:

\[ F_{\text{wall}}(z) = \begin{cases} \frac{1}{z^2} & (\text{for } p = 4) \\ 0 & (\text{for } p < 4) \end{cases} \]

... step time limitation (p = 4 increases too strong)

Power p = 1:

\[ F_{\text{wall}}(z) = \begin{cases} \frac{1}{z^2} & (\text{for } p = 1) \\ 0 & (\text{for } p < 1) \end{cases} \]

Power p = 0.5 [5]:

\[ F_{\text{wall}}(z) = \begin{cases} \frac{1}{z^2} & (\text{for } p = 0.5) \\ 0 & (\text{for } p < 0.5) \end{cases} \]

Both working well

V. RESULTS

Unsteady Couette and Poiseuille flow compared to analytical solutions:

- **Setup:**
  - SPH/STL, 1 = 30 mm
  - SPH/STL, 1 = 6 mm
  - SPH/STL, 1 = 1.2 mm

Unsteady flow in a channel with ridge:

- **With boundary particles:**
  - shear-driven Section A (Re = 0.6)
  - pressure-driven Section B (Re = 0.6)

VI. CONCLUSION AND OUTLOOK

- Our new boundary treatment allows SPH simulations of complex geometries specified in the STL format, which is often used in industrial practice.
- We use this method to analyze mixing phenomena in co-rotating twin screw extruders for pharmaceutical hot melt extrusion. We simulate completely filled and partially filled screw sections as illustrated below.


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