New trends in solid-fluid interactions:

From underground flow to astrophysical applications

MSM

DEMSolutions

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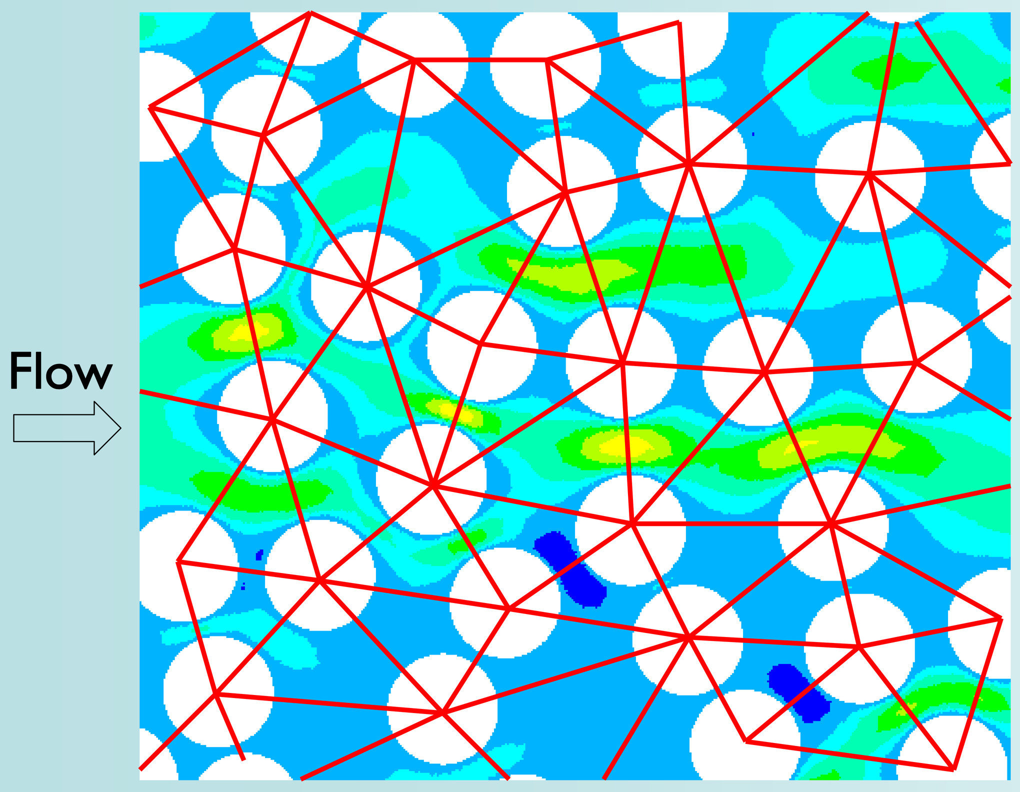
Topics and Goal

Micro-Macro transition: Effect of "micro" parameters (structure) on the "macro" behavior (permeability) of materials

Data structures: Use Delaunay triangulation (DT) for contact detection, structure classification, strain and drag calculation, …

Goal: Combined finite-discrete element method (FEM-DEM)

State of the art - Methodology



DT (in red color) for contact detection AND FE mesh. Color code shows the horizontal velocity field.

- $m_i,\ V_i$: Particle mass, Volume
- $p,\ \varepsilon$: Pressure, Porosity
- β : Friction factor
- $\vec{u},\ \rho$: Fluid velocity, Density
- $\vec{v}_i$: Particle velocity
- $\vec{S}$: Coupling sink term
- τ : Stress tensor
- $F_{contact,i}$: Contact forces
- $F_{pp,i}$: Long-range forces

Solid/Particle motion

$$m_i \frac{d^2 \vec{r}_i}{dt^2} = -V_i \nabla p + \underbrace{\frac{V_i \beta}{1-\varepsilon}\left(\vec{u} - \vec{v}_i\right)}_{=\vec{S}} + m_i \vec{g} + F_{contact,i} + F_{pp,i},$$

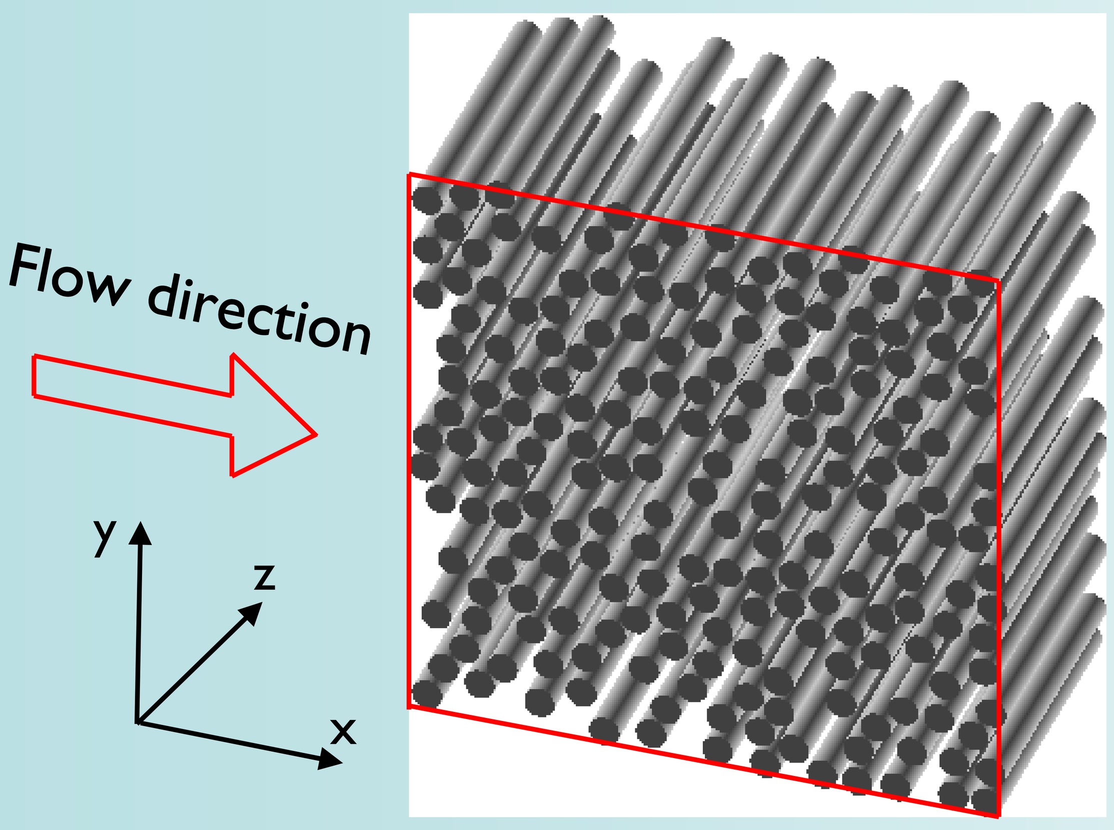
Fluid/Gas motion

$$\frac{\partial}{\partial t}(\varepsilon\rho) + \nabla.\left(\varepsilon\rho\vec{u}\right) = 0,$$

$$\frac{\partial}{\partial t}\left(\varepsilon\rho\vec{u}\right) + \nabla.\left(\varepsilon\rho\vec{u}\vec{u}\right) = -\varepsilon\nabla p - \nabla.\left(\varepsilon\tau\right) - \vec{S} + \varepsilon\rho\vec{g}.$$

Solid-Fluid coupling (two way)

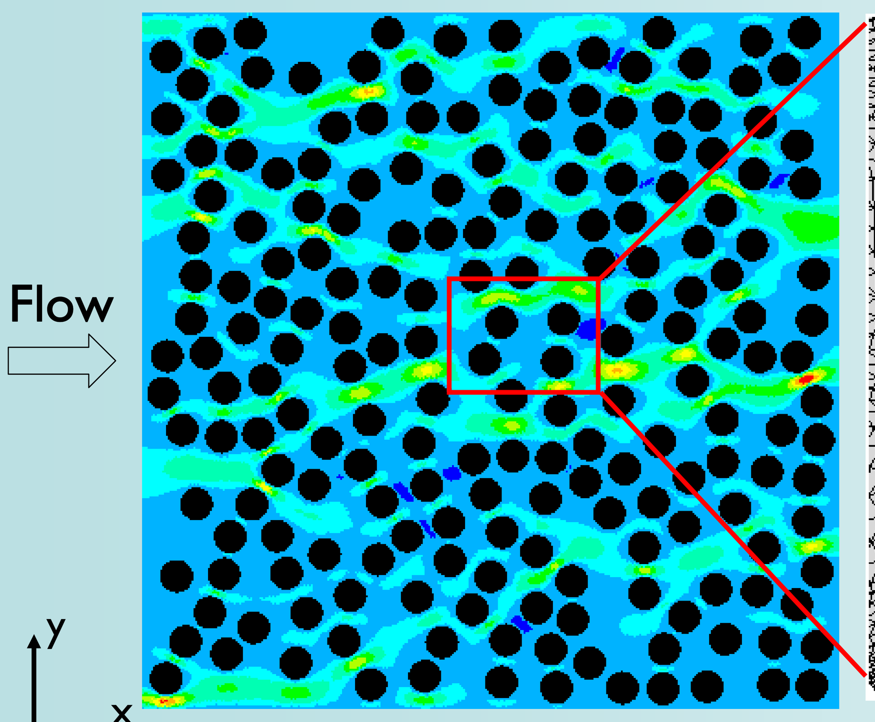
Underground flow - Porous media



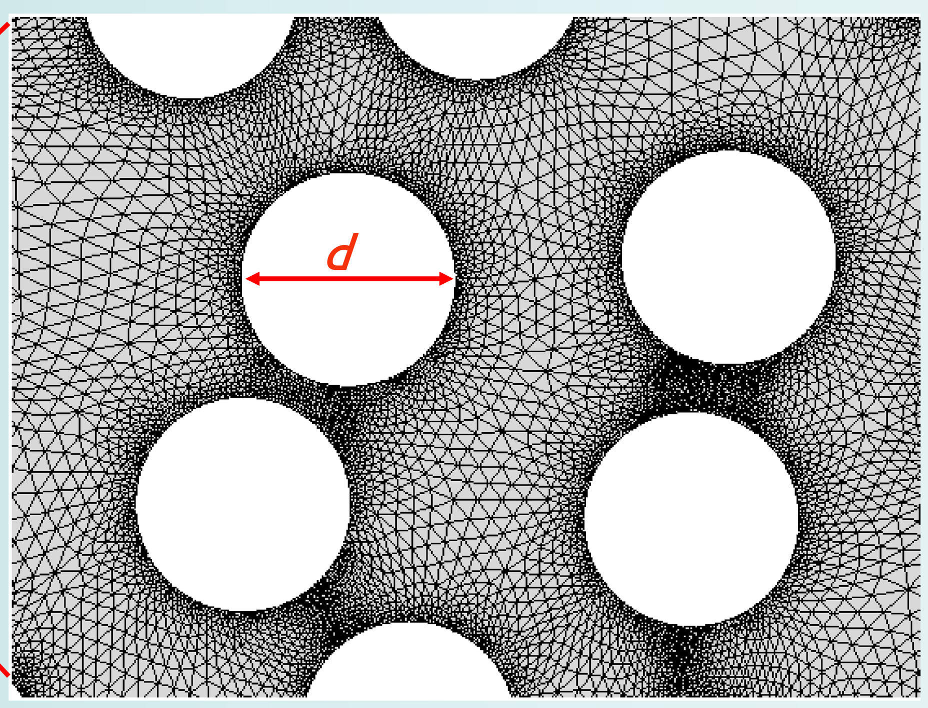
- Fixed particles/fibers
- FEM fluid solver
- Fully resolved (DNS)
- Drag/permeability [1]

Other applications:

- Composite materials
- Suspensions/colloids
- Industrial filters, …

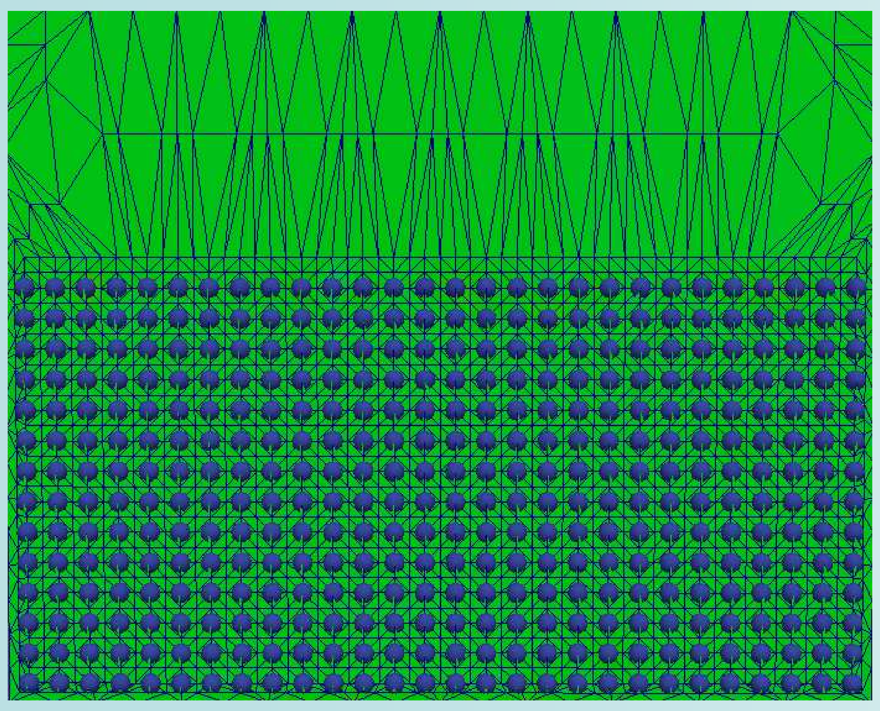


Horizontal (x) velocity field

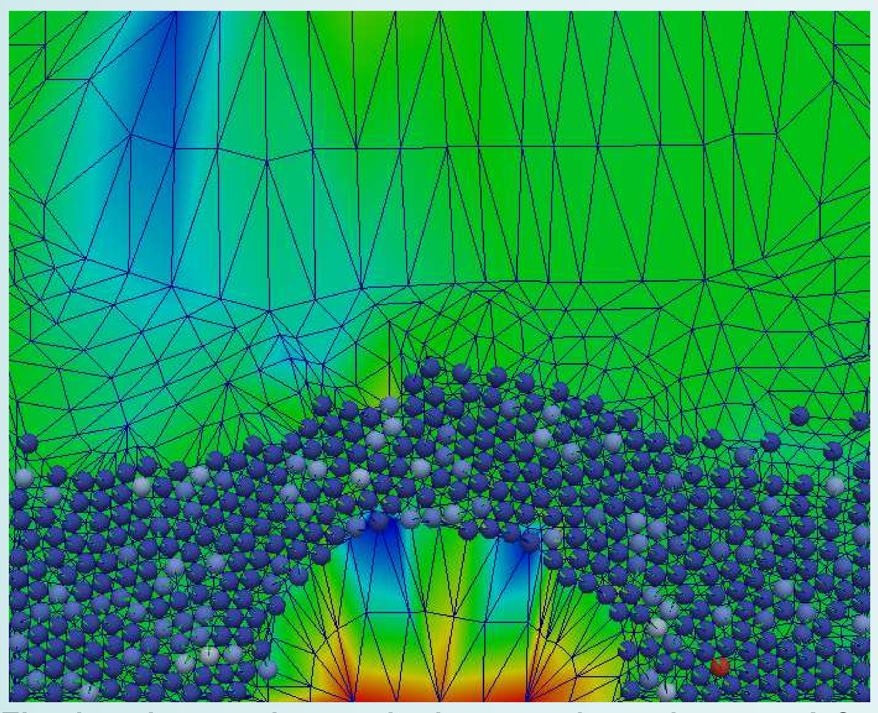


Fine, unstructured, triangular FEM mesh

Industrial applications - Fluidized bed



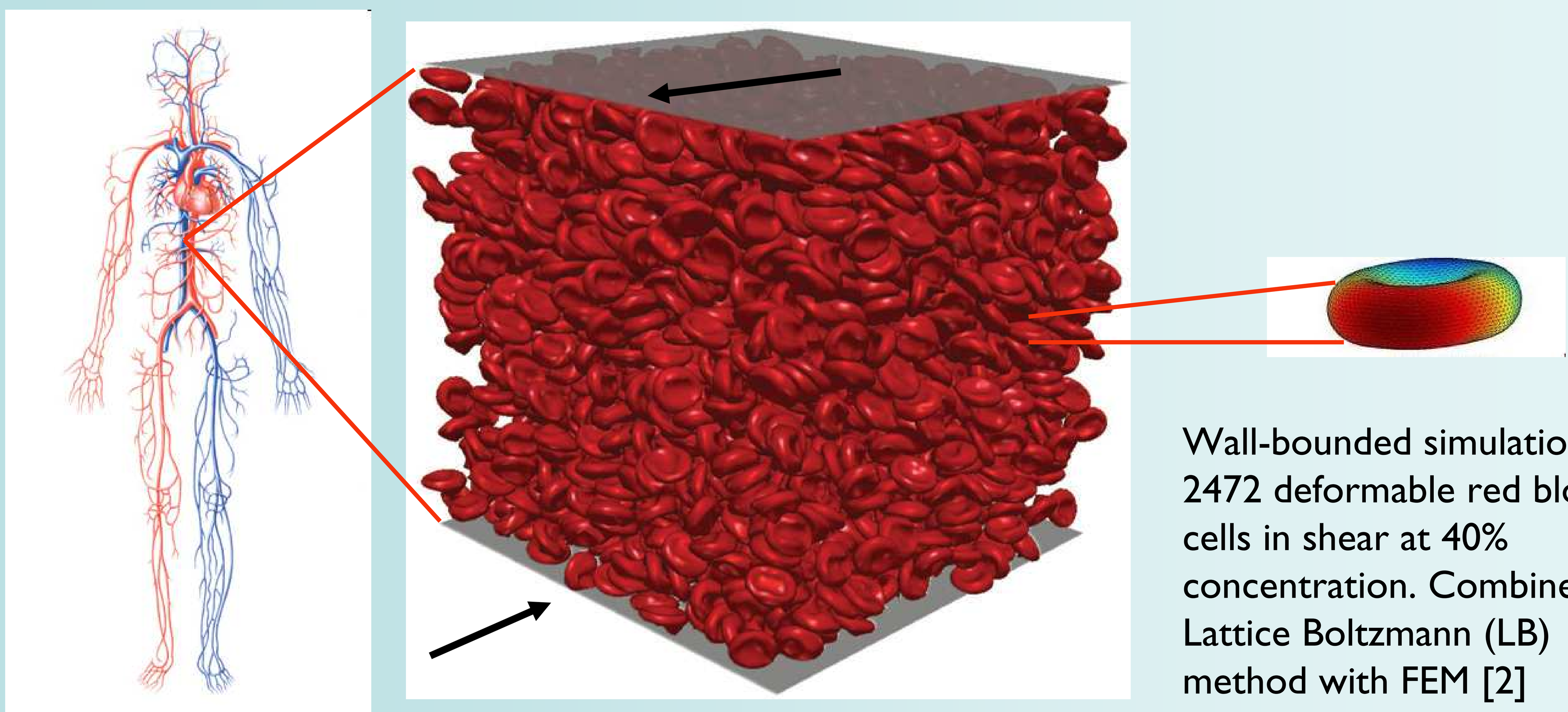
Initial particle positions and corresponding mesh



Fluidized particles with distorted mesh at t=1.2 s

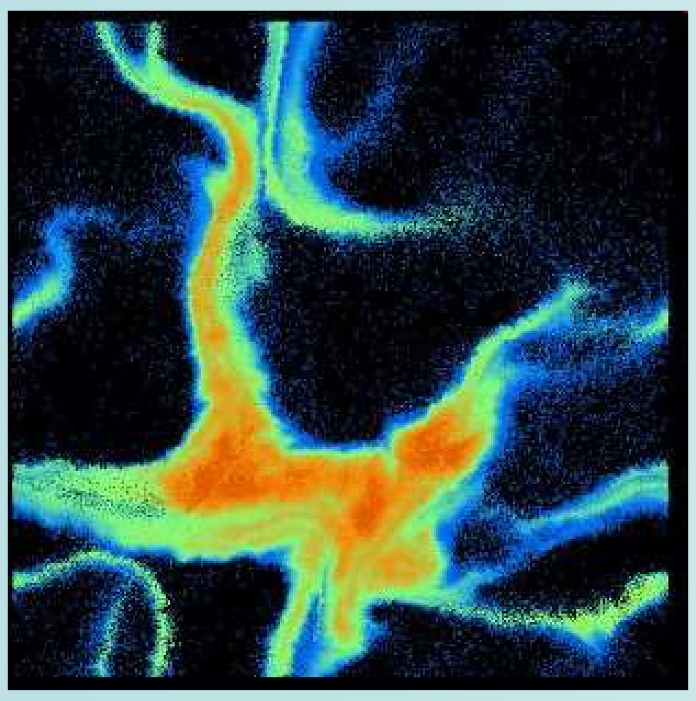
- Unresolved simulation (FEM for fluid and DEM for solid/particles)
- Mesh constructed on particle positions
- Need the drag/permeability closure $\sim\beta\left(\vec{u}-\vec{v}_i\right)$ [1]
- Use DT for contact detection AND FE mesh

Biological applications - Blood flow

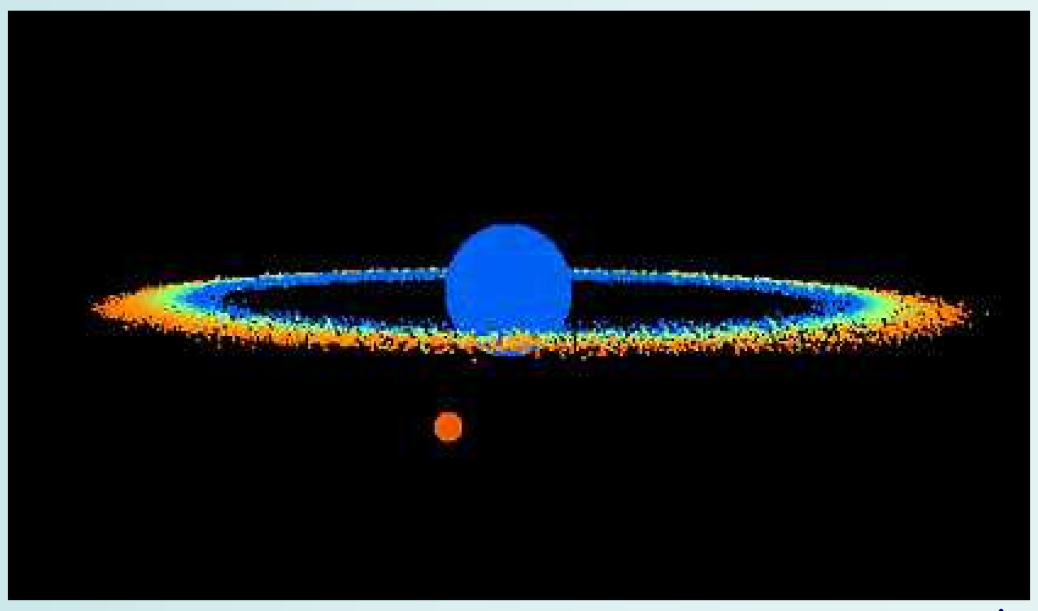


Wall-bounded simulation of 2472 deformable red blood cells in shear at 40% concentration. Combined Lattice Boltzmann (LB) method with FEM [2]

Astrophysical applications - DEM



Freely cooling granular gas [3]



The DEM simulation of astrophysical rings

Conclusions and future work

- ✓ Use DT for contact detection, structure AND drag …
- ✓ Developed a coupled DEM/FEM framework
- ✓ Application in porous media, fluidized beds, blood flow, …
- ➢ Show relevance and validity - compare with other methods

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References

[1] K. Yazdchi, S. Srivastava and S. Luding, Int. J. Multiphase Flow (2011), 37, 956-66.
[2] C.K. Aidun and J.R. Clausen, Annu. Rev. Fluid Mech. (2010), 42, 439–72.
[3] S. Luding, Pramana-J. of Phys. (2005), 64(6), 893-902.