Christoph Schwarzmeier¹, Aniket S. Ambekar², Ulrich Rüde¹,³, Vivek V. Buwa²
¹ Chair for System Simulation, Friedrich-Alexander-Universität Erlangen-Nürnberg
² Department of Chemical Engineering, Indian Institute of Technology Delhi
³ CERFACS, Toulouse

Fully Resolved Lattice Boltzmann Simulations of Turbulent Flow Through Porous Media

Motivation
- Direct numerical simulation (DNS) is time-consuming and expensive
- Accuracy of simulations with turbulence modeling is unclear
  ⇒ Use DNS to assess quality of turbulence models

Multi-physics simulation framework waLBerla [1]
- Designed for massively parallel computing
- Open source: https://walberla.net/
- Performance-optimized kernels via code generation with lbmpy [2]: https://pypi.org/project/lbmpy/

Packed bed creation
- Rigid body dynamics simulation of a sedimentation process
- Resulting packed bed
  - 113 spherical particles with diameter \(d_p\)
  - extension of \(4d_p \times 4d_p \times 7d_p\) with periodicity in two directions
  - porosity \(\varphi = 0.395\)

Simulation of a sedimentation process from left (i) to right (iv). Particles arranged with random displacements fall and into a box (i). Once settled (ii), particles close to the bottom plane are removed (iii). The resulting packed bed geometry is shifted to the center of the domain (iv).

Direct numerical fluid simulation
- Lattice Boltzmann method (LBM) with cumulant collision operator [4]
- Turbulent flow with \(Re = \frac{dp v}{\nu} = 1519\) (kin. visc. \(\nu\), inflow velocity \(v\))
- Particle walls modeled with no-slip boundary conditions
- 3 levels of static refinement reduce total cell count by more than 50 %
- Domain resolved by \(6 \times 10^6\) cells (160 cells per \(d_p\))
- 18 h compute time on 38 864 cores of SuperMUC-NG
- Source code freely available [3]

The displayed grid is 40 % coarser than the one used for the simulation. The packed bed geometry is not displayed and the particles are represented by holes here.

Validation of turbulence models
- Validation of well-established turbulence models: LES WALE, RNG \(k-\omega\), SST \(k-\omega\), RSM-\(\omega\) (in ANSYS Fluent v19.2)
- All models predict the velocity and the gradients of the velocity well:
- Only RNG \(k-\epsilon\) and LES predict turbulence quantities well:

Investigation of transition to turbulence
- Simulations with 80 cells per \(d_p\) to predict onset of turbulence
- Turbulence starts between \(Re = 253\) and \(Re = 506\):

References