Spectral Element Meshing for Packed Beds with Contacting Spheres

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Abstract

Turbulent flow through randomly packed spherical beds is found in many industrial processes in chemical and mechanical engineering [1]. The flow of coolant through packed beds is of particular interest in the design of pebble-bed reactors, and researchers have expressed significant interest in detailed simulations tha can provide insight into heat transfer in new pebble-bed designs [2]. For simulations that resolve turbulent eddies in the flow, high-order discretizations having minimal numerical dissipation and dispersion provide high accuracy with a relatively small number of gridpoints, n. The spectral element method (SEM) [3], which uses local tensor-product bases on curved hexahedral elements, is efficient, with memory costs scaling as $O(n)$, independent of local approximation order N (for n fixed), and computational cost that is only $O(nN)$. Here, $n \approx EN^3$ is the total number of gridpoints for a mesh comprising E elements.

We present an all-hex meshing strategy for the interstitial space in beds of densely packed spheres that is tailored to turbulent flow simulations based on the spectral element method (SEM). The SEM achieves resolution through elevated polynomial order N and requires two to three orders of magnitude fewer elements than standard finite element approaches do. These reduced element counts place stringent requirements on mesh quality and conformity. Our meshing algorithm is based on a Voronoi decomposition of the sphere centers. Facets of the Voronoi cells are tessellated into quads that are swept to the sphere surface to generate a high-quality base mesh. Refinements to the algorithm include edge collapse to remove slivers, node insertion to balance resolution, localized refinement in the radial direction about each sphere, and mesh optimization. A particularly important feature of our new all-hex mesh generator is the use of sphere overlap to avoid singularities at contact points. With this feature, we are able to better control the void fraction, which is important for realizing the correct overall pressure drop in the bed. We demonstrate geometries with 10^2–10^5 spheres using ≈ 300 elements per sphere (for three radial layers), along with mesh quality metrics, timings, flow simulations, and solver performance.

References

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