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Spatiotemporally resolved PIV/SPIV velocity measurements in a MRI facility of randomly packed spheres

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Flows in packed beds are encountered in many engineering applications, such as solar thermal energy storages, chemical catalytic reactors, petroleum and civil engineering, magnetic refrigerators, biological tissues, and pebble-bed nuclear reactors.

Critical challenge of designing packed beds involves understanding the total pressure loss, complex flow fields, heat and mass transfer phenomena occurring within the interstitial regions. Unfortunately, complex geometries and randomly connected void spaces within packed beds have hindered efforts to characterize the underlying transport phenomena.

Geometrical complexity inside of a randomly packed bed represents a challenge to experimental and computational efforts in order to construct transport models that have been previously built upon volume averages of micro-scale parameters, however, should accurately capture the flow behaviors.

Fully leveraging the advantages of this type of packed beds requires a fundamental understanding of flow topology within the randomly packed sphere beds. Multiple points or full-field measurements of flow characteristics at a high level of spatial and temporal resolutions are needed to fully map the complex flow patterns and to provide data at high spatial density to permit accurate volume averaging in the pebble bed.

Texas A&M University is conducting isothermal measurements of pressure drops, flow measurements in a randomly packed spheres experimental facility to support the research on advanced nuclear reactors sponsored by Department of Energy (DOE). The main purpose of these tests is to perform high spatial and temporal resolution measurements, and use the obtained results for code validation and model development.

In this paper, we present high-fidelity velocity measurements using Time-resolved Particle Image Velocimetry (TR-PIV) and Time-resolved Stereoscopic PIV (TR-SPIV) at the pore scales and near the wall boundary in the matching-refractive-index (MRI) facility. This approach allows us to non-invasively probe the flow within packed spheres at the microscopic scales with high temporal and spatial resolutions. Flow characteristics obtained from the TR-PIV and TR-SPIV measurements with various Reynolds numbers are presented. Results include the first- and second-order flow statistics, such as mean velocity, root-mean-square velocity and Reynolds stresses. Effects of the wall boundary and Reynolds numbers to the flow patterns are investigated. Comparisons of the mean velocities, root-mean-square fluctuating velocities, and Reynolds stress component show the increase of flow mixing and turbulent intensities within the gaps between spheres in the packed bed. Sizes of recirculation regions, however, seem to be independent versus an increase of Reynolds numbers. Finally, flow modal decompositions such as proper orthogonal decomposition (POD) and dynamic mode decomposition (DMD) are applied to reveal respectively the statistically dominant and high frequency flow modes.

References

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