An LES method for flow in porous media

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Inertial flows in porous media occur in both natural (e.g., at streambed interfaces with the hyporheic zone) and engineered (e.g., near well bores or in packed-bed reactors) systems. There are a number of approaches for representing the inertial effects of flow in a porous medium, and most commonly these laws involve relate the pressure gradient to the square of the velocity (e.g., the Forchheimer-Ergun equation). Despite the success of these kinds of model relationships, the mechanisms by which momentum is transferred within a bed at high Reynolds numbers (above, say, $N_R = 10$) is not well understood.

We have initiated work in which we are combining experimental visualization of fluid flows in a porous medium with the development of explanatory theory for the net momentum transfer process within the medium. In the theory development component of this work, we are developing a method of volume averaging (MVA) approach to upscaling the momentum balance equations in porous media at high (fully turbulent) Reynolds numbers. Our approach is consistent with Large Eddy Simulation (LES), which decomposes the velocity field into a convolution-filtered (averaged) and deviation components. Unlike Reynolds averaging, the averages in LES are usually spatial averages or a combination of space-time averages. Classical LES averaging, however, has generally not been applied in the vicinity of fluid-solid interfaces where velocity gradients can exhibit discontinuities. We have combined elements of both classical LES theory and MVA theory to provide a framework in which turbulent flows in porous media can be effectively upscaled. Closure in our scheme will be conducted by fully-resolved (i.e., down to the smallest scales of turbulent structure) direct numerical simulation of the flow field, rather than by approximating the sub-grid turbulent structure via one of the conventional models.

Ultimately, our goal is to compare our upscaled representation of momentum transport in a porous medium with the experimental data. We will present a summary of our results to date, including particle imaging velocimetry (PIV) visualization of inertial flow fields in our experimental system, numerical simulations of the flow field on boundary-fitted grids representing the experimental geometry, and developments in the theory.