Adaptive Coupling Techniques for CFD and Porous Flow

Modern computational fluid dynamics (CFD) capabilities can reliably predict the long time behavior of complex systems, provided that the time and length scales governing the various processes involved are comparable. This condition is not satisfied when simulating multiphase gas and moisture fluid flow in an open volume (a tunnel or drift) surrounded by a porous solid medium (a rock mass with embedded moisture). This problem presents unique practical challenges because it cannot be simulated through direct coupling of the physics; the time scales for the gas/moisture flow (seconds) are many orders of magnitude smaller than those for porous media flow (years). Coupling must be achieved efficiently through implementation of periodically applied "hand-off" boundary conditions between two sophisticated computational models.

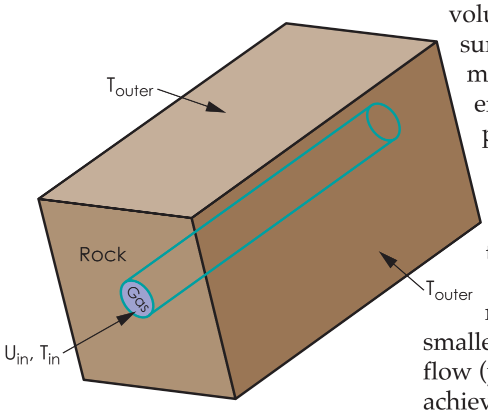

Figure 1. Benchmark problem geometry.

To implement this coupling, we have established a computational methodology to integrate a commercial finite volume CFD package (STAR-CD) and an LLNL hydrological code for porous media (NUFT). The two codes run independently while hydro-dynamic, thermal, and moisture information is periodically exchanged at the gas/rock interface boundary. The immediate application is to characterize the thermal and humidity environment in the drifts of an underground waste repository where the nuclear materials in the waste packages provide high-temperature thermal sources, driving convection and transport in the drift. Successful coupling will result in the ability to predict heat and moisture evolution inside both the drifts and the surrounding rock over thousands of years.

Project Goals

To establish this capability and lay the groundwork for future simulations of complex large-scale

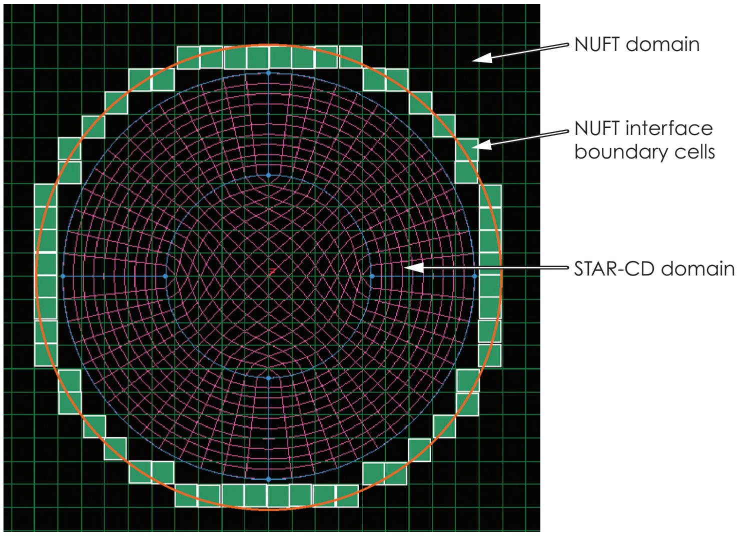

Figure 2. Cross-section of STAR-CD (purple) and NUFT (green) grids. The extended layer resides between the tube wall and the orange boundary. NUFT interpolation cells are shaded green.

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problems, we first needed to select a basic problem representative of the drift tube application to benchmark our methodology. We then determined the most optimum method to link the CFD and NUFT computational grids and transfer information. Our last goal was to demonstrate the convergence of the solution using the coupling methodology.

Relevance to LLNL Mission

This effort provides a flow-modeling capability that can simulate coupled porous flow and CFD. Many LLNL programs, such as the Yucca Mountain Project, DNT, and NAI can benefit from this flow modeling capability.

FY2005 Accomplishments and Results

Our benchmark study consisted of the steady-state conjugate heat-transfer problem of flow through a circular pipe surrounded by a layer of earth (Fig. 1). STAR-CD calculated the flow field within the pipe, and NUFT determined the heat transfer through the porous rock. The difference between the inlet and outer wall temperature boundary condition produces a heat flux between the fluid and the solid medium. We first determined how to transfer information between the two codes by examining various methodologies to overlay the two domains. Since NUFT is limited to structured orthogonal grids, extending the STAR mesh into the surrounding rock and interpolating flow variables onto the NUFT grid was the most effective coupling method. Errors in the interpolation scaled with the size of the NUFT cells.

Figure 2 shows a cross-section of the pipe mesh and surrounding porous domain. Boundary information from the tube walls is transferred into the extended region (bounded by the orange circle) and interpolated onto the NUFT boundary, shown as filled cells. Likewise information from NUFT was projected back onto the extended region of the STAR-CD domain. We wrote scripts to facilitate the data translation and transferred the boundary information through shared files.

With the methodology in place to exchange data between the two solvers we began the iteration process. An initial thermal flux was prescribed on the boundary of the tube along with the inflow conditions, and STAR-CD computed the steady-state solution for the temperature in the drift shown in Fig. 3. We alternately ran STAR-CD and NUFT to steady state and exchanged temperature and thermal flux data at the interface using the coupling methodology. The temperature data along the interface plotted in Fig. 4 indicates the solution is converging, and successfully demonstrates the effectiveness of the coupling algorithm.

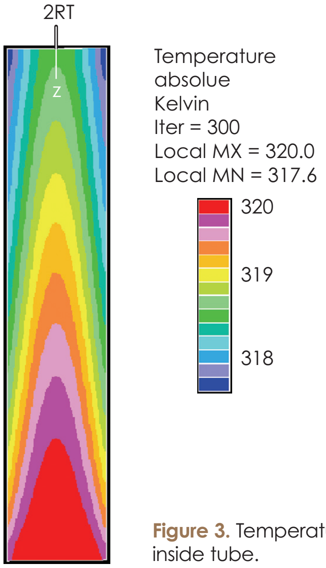

Figure 3. Temperature field inside tube.

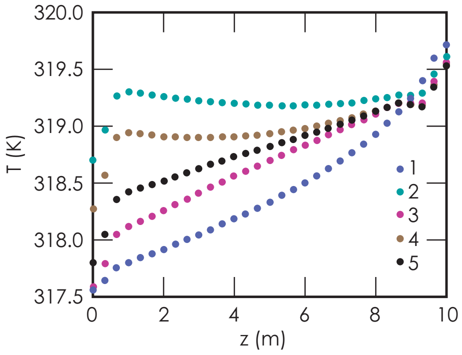

Figure 4. Interface temperature profiles at each iteration.

Related References

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