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Hugh M. McIlroy, Jr.
Donald M. McEligot
Glenn C. McCreery
Keith G. Condie
Robert J. Pink

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Hugh M. McIlroy Jr., Donald M. McEligot, Glenn C. McCreery, Keith G. Condie, Robert J. Pink

Idaho National Laboratory
Idaho Falls, Idaho 83415
Hugh.McIlroy@inl.gov

INTRODUCTION

The Very-High-Temperature Reactor (VHTR) is one of six reactor technologies chosen for further development by the Generation IV International Forum. In addition this system is the leading candidate for the Next Generation Nuclear Power (NGNP) Project in the U.S which has the goal of demonstrating the production of emissions free electricity and hydrogen by 2015. In preparation for the thermal-hydraulics and safety analyses that will be required to confirm the performance of the NGNP, work has begun on readying the computational tools that will be needed to predict the thermal-hydraulics conditions and safety margins of the reactor design.

Meaningful feasibility studies for VHTR designs will require accurate, reliable predictions of material temperatures which depend upon the thermal convection in the coolant channels of the core and other components. Unfortunately, one-dimensional system codes for gas-cooled reactors typically underpredict these temperatures, particularly for reduced power operations and hypothesized accident scenarios. Likewise, most turbulence models in general-purpose CFD codes also underpredict these temperatures.

Matched-Index-of-Refraction (MIR) fluid dynamics experiments have been designed and built to develop benchmark databases for the assessment of CFD solutions of the momentum equations, scalar mixing and turbulence models for typical VHTR plenum geometries in the limiting case of negligible buoyancy and constant fluid properties.

EXPERIMENT DESIGN AND FABRICATION

Figure 1 is a plan view of half the lower plenum of the prismatic VHTR concept along with possible routes of coolant flow. The flow in the lower plenum can locally be considered to be multiple buoyant jets into a confined density-stratified cross flow -- with obstructions. The large shaded circles represent support posts while the smaller ones identify locations of the inlet ducts from the cooling channels in the active core. The arrows give intuitive examples of some paths the flow could be expected to take through the lower plenum from the far side to the outlet duct. The flow rate (or Reynolds number) increases from the right side of the figure to the left as more incoming jets participate.

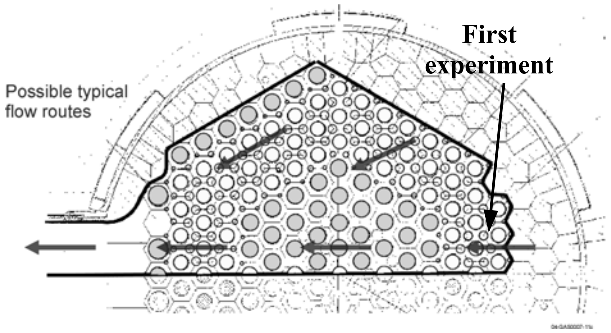

Fig. 1. Examples of possible flow paths in the lower plenum of a typical prismatic VHTR concept.

The first experiment addresses flow in the region on the central plane away from the plenum outlet duct as shown on the right-hand side of Figure 1.

The model shown in Fig. 2 has been fabricated. It is scaled to the geometric dimensions of the NGNP Point Design [i]. This design has been examined to identify flow conditions and geometries over a range from normal operation to decay heat removal in a pressurized cool down. Approximate analysis has been applied to determine key non-dimensional parameters and their magnitudes over this operating range. For example, for turbulent flow in coolant channels, key parameters would include the Reynolds number, Prandtl number, q^+ (non-dimensional heat flux), Bo* (buoyancy) and K_v (streamwise acceleration as density increases). For normal operations the range of outlet Reynolds numbers from coolant channels varied from about 57,000 for a high power core to about 2300 at ten percent power. Over this range, q^+, K_v and Bo* were low relative to their thresholds for significant effects therefore acceleration, buoyancy and gas property variation across the channels are not expected to be important. Additionally, when the Mach number is less than about 0.3, the coolant gas can be considered “non-compressed”, compressibility effects can be neglected and the gas can be modeled as an incompressible fluid with $\Delta\rho/\rho << 1$.

The model consists of a row of full circular posts along its centerplane with half-posts on the two parallel walls to induce flow features somewhat comparable to those expected from the staggered parallel rows of posts in the reactor design. Posts, side walls and end walls are fabricated from quartz to match the refractive-index of the working fluid.

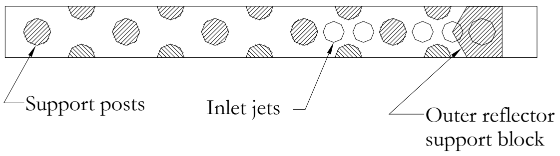

Fig. 2. Plan view of scaled model for the lower plenum experiment.

EXPERIMENTAL APPARATUS

The experiments will be conducted in the Matched-Index-of-Refraction (MIR) Facility at the INL. The benefit of the MIR technique is that it permits optical measurements to determine flow characteristics in passages and around objects to be obtained without locating a disturbing transducer in the flow field and without distortion of the optical paths.

The *innovative advantage* of the INL system is its large size, leading to improved spatial and temporal resolution compared to others. The INL MIR test section has a cross section of about 60 cm x 60 cm and is about two meters long, allowing the use of models of substantial size. Light mineral oil ("baby oil without perfume") is used as the working fluid. The refractive index of the fluid is maintained at the desired value by a parallel temperature control system which maintains a constant temperature in the test section to within 0.05 C. A 3-D PIV system and a two-component LDV system are used to obtain meaningful velocity and turbulence data.

STATUS/PROGRESS

Fig. 3 shows a sample of the results obtained from the initial 3-D PIV measurements. The figure displays average axial velocity (flow is in the negative y direction or vertical plane) at three locations relative to the interface between the inlet jet and model plenum (y = 0). The positive y velocity profiles (y = 18.85 mm and 2.22 mm) were obtained upstream of the inlet jet opening into the model plenum and the profile at y = -5.54 mm was obtained just below the inlet to the plenum.

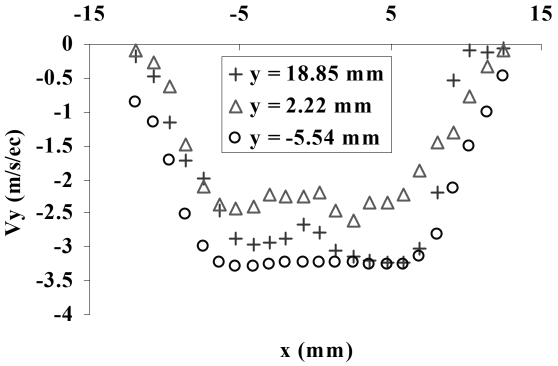

Fig. 3. Average velocity of inlet jet 3 measured by 3-D PIV.

The velocity profiles are typical of uniform, well-developed turbulent flow both in the round inlet duct (at y = 18.85 mm and y = 2.22 mm) and in the early stages of flow into the model plenum (at y = -5.54 mm). The profiles confirm design requirements for well-developed turbulent flow in the jet inlet ducts to model the flow from the inlet ducts into the VHTR lower plenum.

ENDNOTES

1. P. E. MacDonald, J. W. Sterbentz, R. L. Sant, P. D. Bayless, R. R. Schultz, H. D. Gougar, R. L. Moore, A. M. Ougouag, and W. K. Terry, “NGNP Preliminary Point Design – Results of the Initial Neutronics and Thermal-Hydraulic Assessments,” Tech. Rpt. INEEL/EXT-03-00870 Rev. 1 (2003).