

# Heat Transfer Coefficient Variations in Nuclear Fuel Rod Bundles

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Forced convection heat transfer coefficients in rod bundles representative of PWR fuel have been measured at various axial and azimuthal locations to provide the total heat transfer coefficient variation in a rod bundle. These measurements were taken using an established testing technique developed by the authors and their colleagues at Clemson University in South Carolina (USA). The locations measured include upstream of a support grid, within a support grid, and downstream of a support grid. The support grids tested were of different designs. Some of the support grids included mixing vanes attached to the downstream edges of the grid straps.

The single-phase heat transfer performance of a specific grid/vane design is important in that improved performance will delay the onset of nucleate boiling, thereby reducing corrosion and delaying crud-related issues. This paper presents another extension of the work in the area of single-phase heat transfer coefficient (HTC) studies by the authors. Prior work presented at joint ANS/ENS/AESJ/KNS conferences by the authors in this area include:

At the ENS 2003 Topfuel Conference (Wurzburg, Germany), the authors and their colleagues presented the paper "Understanding and Predicting the Flow Field in a Reactor Core" (M. E. Conner, et al.). In that paper, Computational Fluid Dynamics and local heat transfer sensors were used to investigate the single-phase heat transfer coefficient.

At the AESJ 2005 Water Reactor Fuel Performance Meeting (Kyoto, Japan), the authors and their colleagues presented the paper "Heat Transfer Coefficient Testing in Nuclear Fuel Rod Bundles with Mixing Vane Grids" (M. E. Conner, et al.). In that paper, wall temperature measurements were taken in a rod bundle with heated test rods. From this data, the forced convection heat transfer coefficients were determined.

The goal of the present investigation is to study the variation in single-phase heat transfer coefficients in a square-pitch rod bundle. This variation includes both the average axial variation along the bundle (relative to grid location) and the local azimuthal variation around the rod at a given axial elevation. The measurement technique used to obtain this data is the same used in the 2005 paper mentioned above. The conclusion of that paper was that the heat transfer coefficients determined from this technique are reasonable relative to prior

published data and that the data from this facility can be used to determine the axial and azimuthal distribution of heat transfer coefficients downstream of a support grid.

The measurement technique used to determine the heat transfer coefficients in the rod bundle is described below:

The test loop utilizes air to reduce the power requirements of the 5x5 test rod bundle. The inlet air is at room temperature. Therefore, the Reynolds number in the test is much lower than the in-core value. However, using a Nusselt number (Nu) ratio of the local Nu to the fully developed Nu, the air heat transfer data can be compared to water on a consistent basis. The Prandtl number for air at room temperature and water at in-core PWR conditions are essentially the same, providing similitude between the two conditions. Therefore, using air will provide good correlation with in-core heat transfer performance trends.

The rod bundle is heated by electrical heating of the rod wall. The rods are hollow with a relatively thin shell thickness through which electrical current is passed. The hollow cavity of the rod allows room for instrumentation to be inserted inside the tube for temperature measurements. In addition, the thin wall of the rod results in a low temperature drop across the rod wall compared to the temperature drop from the rod outer surface to the flowing air. Therefore, the uncertainty in measuring the ID of the rod wall and projecting to the OD temperature is small.

To measure the ID temperature of the rod wall, a unique thermocouple holder design is used in this testing. Four thermocouples, separated by 90°, are attached to springs that press against the ID of the rod wall. The springs are designed in such a way that the entire thermocouple holder can be moved axially and rotated azimuthally to measure the entire rod ID surface between a grid span.

Results for the heat transfer coefficient obtained from this air testing are presented in the following ways:

Comparisons of the axial distribution of heat transfer coefficients in the rod bundle between prior correlations and different grid/vane designs.

Comparison of the azimuthal heat transfer around the rod at specific elevations in the rod bundle between different grid/vane designs.

Discussion of heat transfer coefficients within the grid.

Based on the heat transfer coefficient variations listed above, a comparison of actual in-core observations of crud patterns to the measured HTC variations will be performed. While crud deposition is a function of a number of parameters including rod heat flux, the HTC is assumed to be a primary factor in explaining why crud disposition is a local phenomenon on nuclear fuel rods. The data from this study will be used to examine this assumption by providing a comparison between HTC variations and crud deposition patterns.