Three-Dimensional Analysis of a Heat and a Coolant Flow in a PWR Fuel Assembly with a Hybrid-Vane Spacer

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1. Introduction

The nuclear fuel assembly used in a pressurized water reactor(PWR) is a rod bundle which is supported by a grid spacer. The fuel spacer affects the coolant flow distribution in the fuel rod bundle, and so the spacer geometry has a strong influence on a bundle's thermal-hydraulic characteristics, such as the critical heat flux and pressure drop. In particular, the integral flow deflecting vanes on the grid spacer can improve the departure from a nucleate boiling(DNB) performance by increasing the coolant mixing and the rod heat transfer ability downstream of the vanes.

The objective of this study is to examine the heat transfer characteristics in the fuel assembly with a hybrid-vane spacer[1]. The computational fluid dynamics (CFD) code, CFX-10[2] is used to perform the three-dimensional analysis of the flow mixing and heat transfer in a rod bundle with and without a flow-mixing vane.

2. Numerical Methods

2.1 CFD Model and Boundary Conditions

The PWR fuel assembly consists of fuel rods which are arranged in square pitched arrays with the coolant flowing axially through the subchannels formed between the rods. By using the symmetry of the hybrid-vane pattern as well as the flow, four subchannels are modeled for the CFD analysis to reduce the size of the computational model(Fig.1). In addition, the quadrant subchannel is also modeled for the CFD analysis of the fuel assembly without a mixing vane spacer. The ratio of the pitch to rod diameter is 1.33 which is similar to the commercial PWR fuel assembly. The hybrid-vane spacer model used 2.5 million nodes with tetrahedrons, prisms and hexahedrons as shown in Fig. 2. The no-spacer model used 121,000 nodes with hexahedrons only.

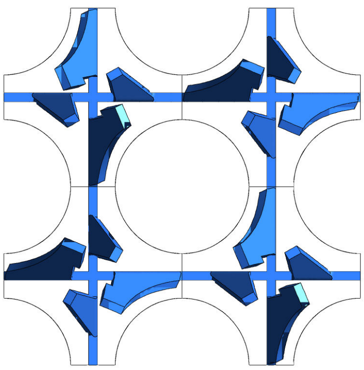

Figure 1. CFD model for the fuel assembly with the hybrid vane.

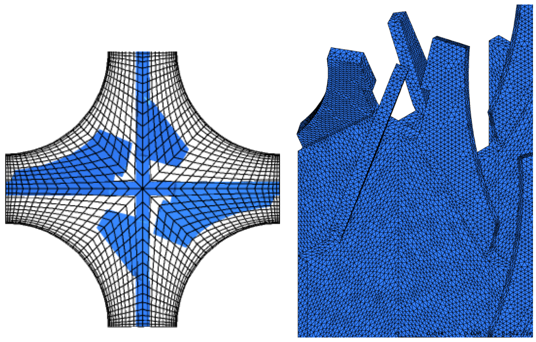

Figure 2. Computational mesh for the hybrid-vane spacer model.

For the hybrid-spacer model with four subchannels in Fig. 1, the fully developed profiles of the velocity, temperature and turbulence parameters are used at the inlet boundary upstream of the spacer. A constant pressure is applied at the outlet boundary downstream of the spacer. A periodic condition is used at the side boundaries where an inflow as well as an outflow are allowed. Constant heat flux and no slip are used at the fuel rod surface.

For the no-spacer model with a quadrant subchannel, a fully developed flow is also applied at the inlet boundary and a constant pressure at the outlet. Symmetric flow is assumed at the side boundaries since a lateral flow is judged to be insignificant. Constant heat flux and no slip are also used at the fuel rod surface.

2.2 Computational Procedure

A subcooled water at 150 bar is used as a working fluid. The fluid bulk velocity and temperature at the inlet boundary are 5 m/sec and 308 ^{o}C, respectively. The constant heat flux of 600 kW/m^2 is applied along the fuel rod. The standard k-e model is used for a turbulence model. The SIMPLEC algorithm was used to solve the velocity-pressure coupling and the high resolution scheme was used to descretize the convection term. The iterative calculation was terminated when the residual for all the governing equations was less than 10^{-7}.

3. Results and Discussions

Figure 3 shows a coolant mixing caused by the hybrid vane at $5D_h$(equivalent flow diameter) downstream of the spacer grid. Large swirl and crossflow are formed inside the subchannel and between the adjacent subchannels. The maximum secondary velocity is approximately 34% of the bulk coolant velocity.

Figure 4 shows the calculated temperature distribution at the fuel rod for the hybrid-vane spacer and no spacer. The case for the hybrid-vane spacer resulted in the average fuel-rod temperature being lower than the no-spacer case by 1-5 ^oC. It is however noted that a local hot spot appears to be observed in the hybrid-vane case. This is due to the secondary flow occurring in the opposite direction. The circumferential variation of the fuel-rod temperature is estimated as 20 ^oC and 6 ^oC for the hybrid-vane and no-spacer cases, respectively. It is also noted that the peak fuel-rod temperature occurs at the gap for the no-spacer case but at that off the gap for the hybrid-vane case.

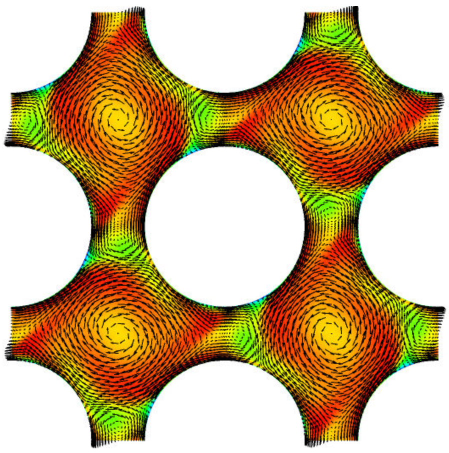

Figure 3. Flow mixing caused by the hybrid vane.

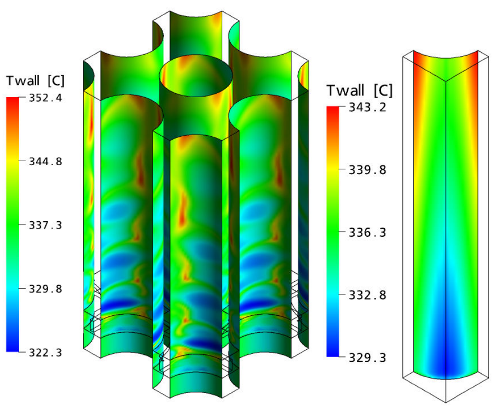

Figure 4. Temperature distribution at the fuel rod.

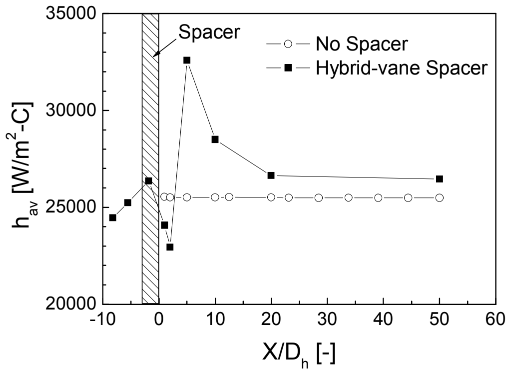

Figure 5. Axial variation of heat transfer coefficients in a nuclear fuel assembly.

The axial variation of the average heat transfer coefficients is compared in Fig. 5. The heat transfer coefficient with the hybrid-vane spacer significantly increased downstream of the spacer while there was almost no variation for the no-spacer case. The hybrid vane is predicted to increase the heat transfer coefficient by 27% and 4% at $5D_h$ and at $20D_h$ downstream of the spacer, respectively.

4. Conclusion

A three-dimensional analysis of a heat and a coolant flow in a PWR fuel assembly with the hybrid-vane spacer has been performed by using the CFD method. The hybrid vane induced a swirl and crossflow which enhanced the heat transfer as well as the coolant mixing. Even if the local hot spot is observed for the hybrid-vane case, it is confirmed that the hybrid vane increases the heat transfer to the coolant from the fuel rod and subsequently lowers the average fuel-rod temperature. Hence, the hybrid vane is expected to enhance the DNB performance of a nuclear fuel assembly once applied.

Acknowledgement

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