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Thermal-Hydraulic Performance of a Hybrid Vane and Split Vane in a PWR Fuel Assembly

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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 a spacers' 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 a grid spacer can improve the departure from a nucleate boiling(DNB) performance by increasing the coolant mixing rate and the rod heat transfer ability downstream of the vanes.

This paper compares the coolant mixing rate and the heat transfer coefficient in a fuel assembly with a hybrid-vane spacer[1] and a split-vane spacer[2]. The computational fluid dynamics (CFD) code, CFX-10 is used to perform the three-dimensional analysis of the flow mixing and heat transfer in the fuel assembly.

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 mixing-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). It is noted that two spacers are included in this CFD model.

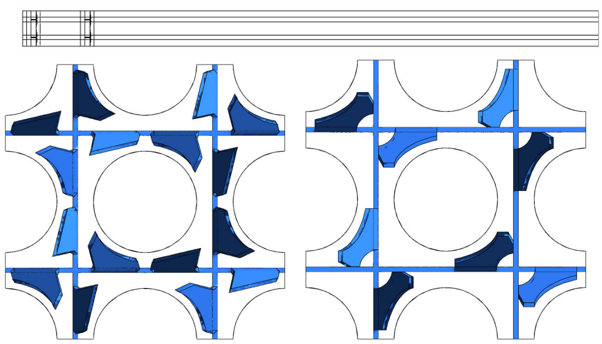

Figure 1. Four-subchannel CFD models for the hybrid vane (left) and the split vane(right).

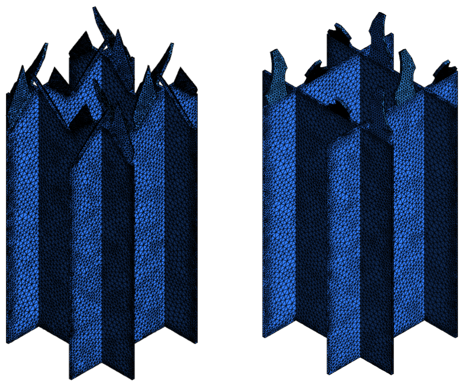

Figure 2. Computational meshes for the hybrid-vane(left) and split-vane(right) spacers.

The ratio of the pitch to rod diameter is 1.35 which is similar to the commercial PWR fuel assembly. The span between the spacers is 35 times that of the hydraulic diameter(D_h) of the fuel bundle. The model length downstream of the second spacer is 300D_h. This is to assure a fully developed flow at the outlet boundary of the CFD model. Currently, the CFD models for both the hybrid vane and the split vane use 4.8 million nodes with tetrahedrons, prisms and hexahedrons. Figure 2 shows the meshes for the hybrid-vane and split-vane spacers.

Fully developed profiles of the velocity and turbulence parameters, and a constant temperature are used at the inlet boundary upstream of the first spacer. A constant pressure is applied at the outlet boundary far downstream of the second 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.

2.2 Computational Procedure

A subcooled water at 158 bar is used as a working fluid. The fluid bulk velocity and temperature at the inlet boundary are 5 m/sec and 295 ^oC, respectively. A constant linear heat rate of 20 kW/m 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^{-6}.

3. Results and Discussions

Figure 3 compares the coolant mixings caused by the mixing vane at $5D_h$ downstream of the first spacer. The hybrid vane generates a large swirl inside the subchannel and a small crossflow between the adjacent subchannels. The split vane causes a large crossflow and two small swirls rotating in opposite directions inside the subchannel.

Figure 4 shows the calculated temperature distribution at the fuel rod for the hybrid-vane and split-vane spacers. It is noted that a hot spot appears to be observed in both cases. This is due to the secondary flow occurring in the opposite direction. Figure 5 compares the circumferential variation of the fuel-rod temperature at $5D_h$ showing a different local hot spot. It also shows a temperature difference of as much as 15 ^oC for both cases. It was however found that far downstream, e.g., > $20D_h$, the split vane resulted in a higher rod temperature.

The axial variation of the heat transfer coefficient(HTC) is compared in Fig. 6. The HTCs were obtained by using circumferentially averaged, maximum and minimum rod temperatures, respectively. The hybrid vane predicted a minimum value at 25 D_h being about 4% higher than the split-vane case. This means that the split vane could generate a hotter spot which will deteriorate the DNB performance of a fuel assembly.

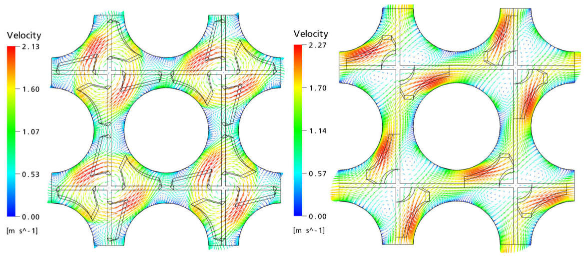

Figure 3. Swirl and crossflow caused by the hybrid vane and the split vane.

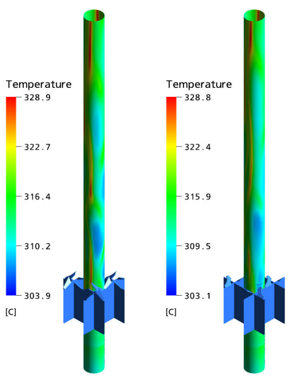

Figure 4. Fuel rod temperature with the hybrid vane(left) and the split vane(right).

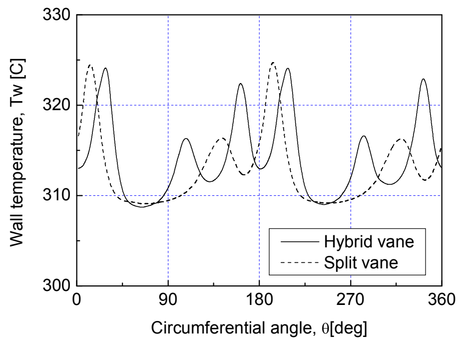

Figure 5. Circumferential variation of the fuel-rod temperature.

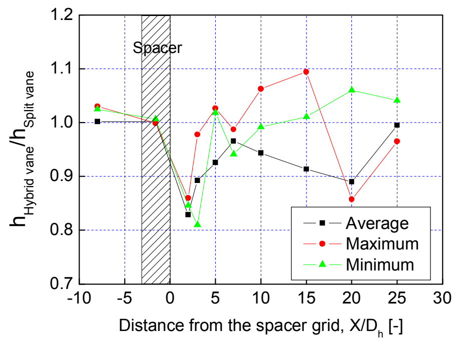

Figure 6. Axial variation of the heat transfer coefficient.

4. Conclusion

A CFD analysis of a heat and a coolant flow in a PWR fuel assembly with hybrid-vane and split-vane spacers has been performed. The hybrid vane induced a large swirl near the spacer while the split vane induced a large crossflow. Both cases resulted in a hot spot but showing axially and circumferentially different variations. The split vane may slightly increase the average HTC over the hybrid vane. However, the hybrid vane gave a higher HTC(i.e., lower rod temperature) in a hot spot which would eventually increase the DNB performance of a nuclear fuel assembly.

Acknowledgement

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[2] Holloway, M. V. et al., "The Effect of Support Grid Design on Azimuthal Variation in Heat Transfer Coefficient for Rod Bundles," J. Heat Transfer, Vol. 127, p.598, 2005.