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Analysis of Turbulent Heat Transfer Downstream of Mixing Vanes with Tip in Subchannel of Nuclear Reactor

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1. Introduction

Mixing vanes attached to spacer grid in rod bundle subchannel produce highly three-dimensional and strongly turbulent flow, which is effective to enhance convective heat transfer. Development of computational fluid dynamics (CFD) makes it possible to analyze the complex three-dimensional flow structure precisely, which is very instructive in understanding thermal-hydraulics of the phenomena.

There have been a lot of researches to investigate the flowfield downstream of mixing vane experimentally and numerically. Among numerical works, Karoutas et al. (1995), In et al. (1998), and Cui and Kim (2002) performed numerical analysis using commercial CFD code to find the turbulence structure induced by mixing vane. Imaisumi et al. (1995) presented a method for three-dimensional analysis of the flow in a PWR fuel assembly.

The most important factors in enhancing heat transfer in subchannels, are production of turbulent kinetic energy, cross-flow mixing in subchannel, and development of secondary flow. These factors can be analyzed precisely by solving three-dimensional Reynolds-averaged Navier-Stokes equations (RANS).

The present work aims at evaluation of the effects of tip attached to the end of the mixing vane on turbulent convective heat transfer downstream of mixing vane in subchannel of nuclear reactor with three-dimensional RANS analysis. SST model is selected as a turbulence closure. 'PLUS7' Mixing vane with tip is tested in comparison with the mixing vane without tip. In addition, the effects of tip angle are also tested.

2. Methods for Flow Analysis

Shape of the mixing vane with tip are shown in Fig 1. The greek, α is bending angle, and β is tip bending angle. The height of the spacer grid is 40 mm. the computational domain extends from 40 mm upstream to 530 mm downstream of the spacer grid. Thus, the length of the domain is 610mm. With a fuel rod diameter of 9.53 mm and pitch of 12.7 mm, the hydraulic diameter D_h of the subchannel is 12 mm and the thickness of the spacer grid, 0.4 mm. But, surface dimples and grid springs are neglected to avoid computational complexity.

A commercial CFD code, ANSYS CFX 11.0 (2007) , which employs unstructured grid, has been used for numerical analysis. Shear Stress Transport (SST) model with automatic wall treatment is used as a turbulence closure. As a boundary conditions, uniform flow at inlet and constant pressure at exit are specified. Adiabatic condition is used at the surfaces of mixing vane and spacer grid, and constant heat flux condition is used at the surfaces of fuel rod. At inter-channel boundaries, symmetric condition is applied upstream of mixing vane, but downstream of the vane periodic condition is used to allow the cross flow mixing. Average axial velocity in subchannel is 6.97 m/s, which is similar to the velocity of steady operation of nuclear reactor. Reynolds number of the flow is 80,000.

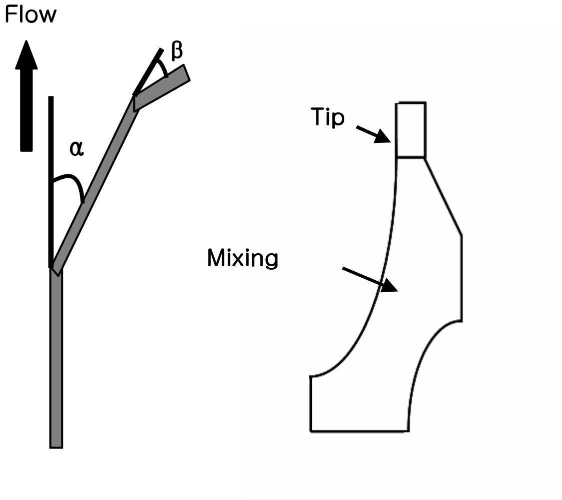

Figure 1. Geometry of the 'PLUS7' mixing vane with tip

3. Result and Discussion

The evaluation of performances of mixing vane without tip (only α=12°) and with tip (α=12°, β=24°) is carried out. Fig. 2 shows the axial distributions of local Nusselt number. The Nusselt number is normalized by Nu_0, i.e., Nusselt number without mixing vane. Passing through the mixing vane, heat transfer coefficient increases rapidly by forced mixing until the peak point located before $8D_h$, but decreases thereafter. Mixing vane with tip shows better performance in enhancing the heat transfer.

Fig 3 shows the comparison of swirl flow rate with various tip angles along the swirl lines. After passing through the mixing vane swirl flow rate is decreasing. But the mixing vane which has more bending angle shows better performance of swirl flow rate.

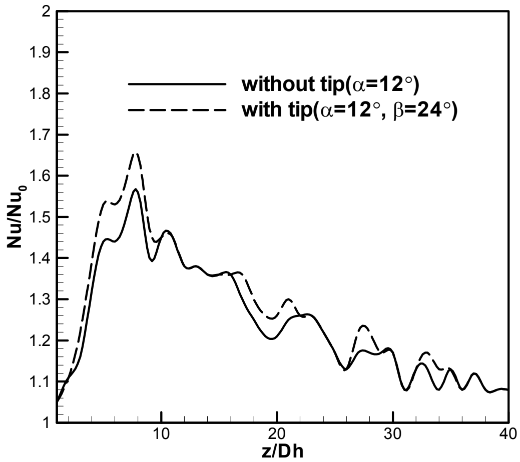

Fig. 2 Comparison of Nusselt number distributions in mixing vane with no-tip and with tip

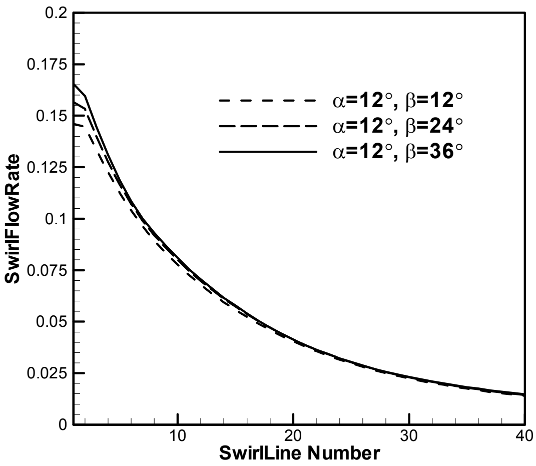

Fig. 3 Comparison of swirl flow rate with various tip angles

Fig. 4 shows the axial distributions of local Nusselt number for various tip angles. Total 3 cases are tested. All the cases, bending angle α is fixed, and tip angle β is varied with 12°, 24° and 36°. Mixing vane with tip angle, 36° shows the best performance in enhancing the heat transfer. But there is little difference in pressure drop.

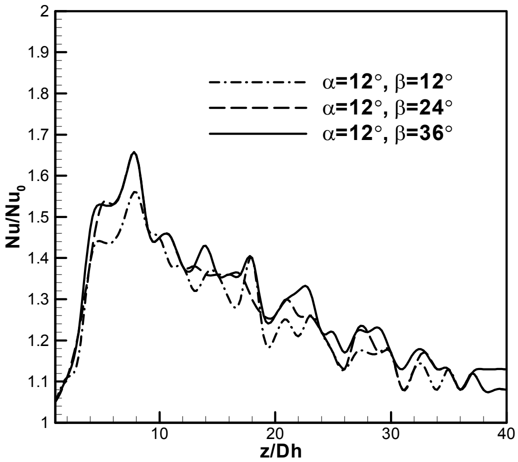

Fig. 4 Comparison of Nusselt number distributions with various tip angles.

4. Conclusion

Flow and heat transfer characteristics of mixing vanes with tip were analyzed by three-dimensional RANS analysis. In the results of analysis of convective heat transfer downstream of mixing vane, the mixing vane with tip shows better performance in comparison with the mixing vane without tip. Mixing vane with larger bending tip angle shows better overall performance in enhancing the heat transfer. But, pressure drop is almost same. Optimization techniques coupled with 3-D RANS analysis will optimize the shape of mixing vane with tip which enhances heat transfer rate and lower pressure drop.

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