The Effect of the Mixing Vane Grid on the Local Behaviors of the CHF

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1. Introduction

Numerous studies have shown that the mixing vanes of the spacer grids in a nuclear fuel rod bundle increase the Critical Heat Flux (CHF) significantly. Experimental and numerical studies for flow pattern and turbulent characteristics in a single phase condition, void fraction distribution and thermal mixing in a two-phase flow and so on have been performed by many researchers for a spacer grid with or without mixing vanes. Chang et al.[1] measured the detailed flow velocities in an enlarged 5x5 rod bundle array with vaned spacer grids by using a Lager Doppler Velocimetry. The effect of the grid assembly mixing vanes on both the value of a CHF and the azimuthal location of a DNB was performed on electrically heated, 5x5 square pitched, vertical round bundles for a Freon-12 coolant by Crecy[2]. In et al.[3] they also showed from the results of the computational fluid dynamics(CFD) code, CFX-10 that the hybrid vane generates a large swirl inside a subchannel and a small crossflow between the adjacent subchannels and the split vanes cause a large crossflow and two small swirls rotating in opposite directions inside the subchannels. The water-equivalent data of the CHF results without a mixing vane from out test loop have been compared with actual water CHF data and the typical bundle CHF prediction correlations by Akhtar et al.[4].

The main objective of this work is to evaluate the local behaviors of the CHF of a hybrid vane grid and a split vane grid and to compare the water-equivalent CHF data generated from the fluid-to-fluid modeling with the EPRI CHF correlation. Three kinds of rod bundles were tested for the above objectives: no mixing vane grids, the hybrid mixing vane grids, and the split mixing vane grids. To measure the CHF data, 5x5 rod bundle experiments were conducted in the FTHEL. The CHF prediction was analyzed using a MATRA code.

2. Experimental Apparatus and Analysis

In the FTHEL facility, working fluid of R-134a is circulated by two non-seal canned motor pumps connected in series through a flow-meter, a pre-heater, an inlet throttling valve, a test section, a condenser and a cooler. 25 rods are electrically heated directly with a DC power. The wall temperatures are obtained from the T/Cs installed at the end of the 25 heater rods which have a uniform axial power shape. The radial power distribution is non-uniform. The grid span of 564 mm is longer than the actual one (400 mm) for the 16x16 fuel bundle of the KSNP. The experiments were performed in ranges of the inlet pressure, P_{in} = 2000 ~ 3000 kPa, mass flux, G = 1000 ~ 4000 kg/m^{2}s, and inlet subcooling, Δh_{in}= 10~ 55 kJ/kg

The basic similarities for a fluid-to-fluid modeling are the geometric, thermodynamic, and hydrodynamic similarities. For modeling the mass flux, the empirical compensated distortion parameter of Ahmad has been adopted. The dimensionless CHF base on the exit critical quality is expressed as followings.

$$\frac{q''_{CHF}}{G \cdot h_{fg}} = f\left(\psi_{CHF}, X_C, \frac{\rho_l}{\rho_v}, \frac{L}{D}\right) \qquad (1)$$

3. Results and Discussions

3.1. Single-phase heat transfer

The single-phase heat transfer characteristics have been calculated from the wall temperature of the heat balance tests. The results are normalized by each averaged wall temperature as shown in Fig. 1.

The averaged deviations are 5.3% for no mixing vane, 0.8% for the split mixing vanes, and 0.9% for the hybrid mixing vanes. The deviation of the temperature distribution is decreased to below 1/5 by the installation of the mixing vanes and the deviation of the averaged wall temperature on the split vanes is slightly reduced when compared with that of the hybrid vanes. The highest wall temperature is as high as 20% for no mixing vanes, 1.6% for the split vanes, and 2.2% for the hybrid vanes compared to average temperature. From the single-phase heat transfer results of In et al., the split vane may slightly increase the averaged heat transfer coefficient over the hybrid vane. The turbulent mixing between subchannels by the split vanes is better than that by the hybrid vane. But these results for the single phase heat transfer are inconsistent with the results of the CHF performance.

3.2 Radial position of the CHF

The radial positions where occurred a CHF on the rods are summarized in Fig. 2. The positions are grouped into five groups; the thermocouples at a center rod(I), inner side of the middle rods(II), the outer side of the middle rods(III), inner side of the outer rods(IV), and outer side of the outer rods(V). For 74 data sets of the no mixing vane, a CHF of 73% appears first on the central rod and 23% appears first on middle rods. For 58 data sets of the hybrid vane, a CHF of 28% appears first on the central rod and 70% data appear first on the middle rods. The increases of an enthalpy mixing between the center and the middle subchannels by the mixing vane cause enhancements of the CHF as from the results. For 39 data sets of the split vane, a CHF occurs in the whole region and a CHF of 20% appears first on the outer rods(region V) as well. As suggested by In et al. and Chang et al., the hybrid mixing vane dominantly creates a swirl flow in each subchannel and the split vane dominantly generates a cross flow between subchannels. The large-scale cross flow by the split vane leads to an enthalpy increase in the outer subchannels and this is considered as one of the main reasons for an increase of the CHF occurrences at the outer subchannels.

3.3 Fluid-to-Fluid Modeling

The water-equivalent CHF data generated from the R-134a CHF data are compared with the EPRI correlation. Fig. 3 shows the overall results for the ratios of the DNB for the Prediction-to-Present data versus Ahmad's parameter. The predicted CHF from the EPRI correlation underestimates by 0.9 for the no mixing vane, 0.88 for the turbulent mixing factor, β=0.02, and 0.92 for β=0.03. In the experiment, the CHF performance of the hybrid mixing vane grid is superior by about 14.4% on average to that of the no mixing vane grid. In the analysis, however, the increase of the CHF performance is 9.2% for β=0.02 and 14.1% for β=0.03, respectively. In the subchannel analysis code, the mixing vane effect is only adopted through the turbulent mixing factor. It is not sufficient to represent the CHF behaviors derived from the mixing vane shape through only a turbulent mixing factor, β. The flow characteristics by the vane shapes must be considered to understand the CHF enhancement by the mixing vanes.

4. Conclusion

From the experiment and analysis the following conclusions can be drawn:

The turbulent mixing between subchannels in the single phase heat transfer by the split vanes is better than that by the hybrid vane. But these results for the single phase heat transfer are inconsistent with the results of the CHF performance.

The large-scale cross flow by the split vane leads to an enthalpy increase in the outer subchannels and this is considered as one of the main reasons for an increase of the CHF occurrences at the outer subchannels.

In the subchannel analysis, it is not sufficient to represent the CHF behaviors derived from a mixing vane shape through only a turbulent mixing factor, β. This is regarded as a major factor for a great prediction of a CHF.

Acknowledgment

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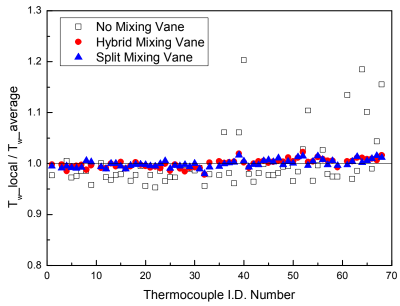

Fig. 1 Single-phase heat transfer

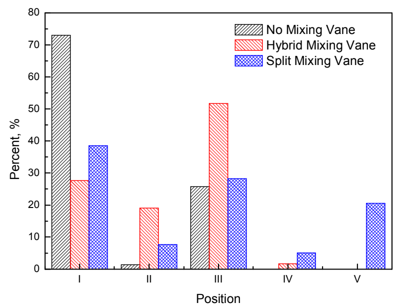

Fig. 2 Radial Position of the CHF

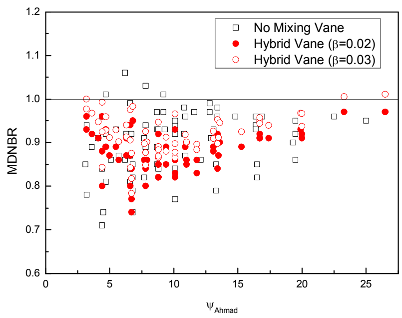

Fig. 3 Predictions of the MDNBR