CHF Performance of Hybrid Mixing Vane Grid (II)

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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 [1,2,3]. This increase is known to mainly come from the enforced turbulence and lateral flow to homogenize the local enthalpy imbalance in the coolant throughout the downstream of the mixing vanes. These effects can suppress the occurrence of a CHF. However, the amount of the CHF enhancement depends strongly on the design of the mixing vanes such as the vane shape and vane bending angle.

Over a couple of decades a split mixing vane has been widely used by most nuclear fuel vendors. As shown in Figure 1 (a), the split mixing vanes are formed as pairs such that each one is bent in an opposite direction. Recently a new mixing vane design was developed for an advanced spacer grid at KAERI. It's called a Hybrid Mixing Vane [4] as shown in Figure 1(b), which comprises two types of vanes; primary vanes and secondary vanes. The primary vanes are to generate a cross flow between subchannels, while the secondary vanes are to create a swirl flow within the subchannels.

The main objective of this work is to evaluate the CHF performance of the hybrid vane grid [5] and to compare it with that of a split vane grid. 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(Freon Thermal Hydraulic Experiment Loop) at KAERI. The test matrix sufficiently covers the PWR operating conditions for water equivalence.

2. Experimental Apparatus and Procedure

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 actual one (400 mm) for the 16x16 fuel bundle of the KSNP. The parameters of the test section are listed in Table 1.

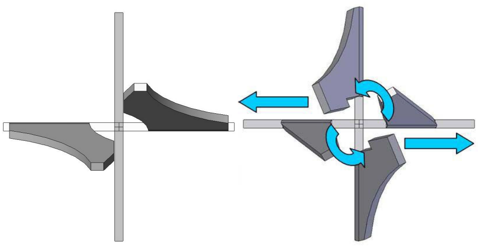

Fig. 1 (a) Split vanes (b) Hybrid vanes

Each experiment was performed by maintaining the following system conditions as constant: inlet pressure, inlet temperature, and mass flow rate. The power to the test section is increased until a temperature excursion is observed by one or more thermocouples, or the maximum temperature is 35 ^oC higher than the saturation temperature.

The experiments were performed in ranges of the inlet pressure, P_{in} = 2000 ~ 3000 kPa, mass flux, G = 1000 ~ 3000 kg/m^{2}s, and inlet subcooling, Δh_{in}= 10~ 55 kJ/kg, which simulate the PWR operating conditions for a water equivalence through a fluid-to-fluid modeling.

3. Results and Discussions

For a comparison purpose, the test conditions, such as the test matrix, the power distributions of a rod bundle, the distance between the spacer grids, and so on were maintained the same as much as possible for the three rod bundles.

Figure 2 shows the CHF results along with the mass flux at the pressure of 3000 kPa. As expected, at a low mass flux of 1000 kg/m^{2}s, the differences in the CHF between the hybrid and the split vane grids are fairly small. But above a mass flux of 1500 kg/m^{2}s the inherent flow mixing characteristics of the mixing vanes are revealed so as to make a distinction. The hybrid mixing vane grid shows higher CHF results than the split mixing vane grid. At a mass flux of 3000 kg/m^{2}s and an inlet subcooling of Δh_{in}=25 kJ/kg, the hybrid mixing vane grid shows a higher CHF of about 6.3%

Table 1. Parameters of the 5x5 bundle test section

Parameter	5x5 Bundle
Total number of heated rods	25
Rod pitch (mm)	12.85
Rod diameter (mm)	9.5
Heated length (mm)	2000
Rod to wall gap (mm)	3.25
Corner radius (mm)	3.0
Flow area (mm^2)	2762.98
Axial power distribution	Uniform
Distance between spacer grids (mm)	564
Radial power distribution	
Peaking factor of center 9 rods	1.123
Peaking factor of side 16 rods	0.931

than the split mixing vane grid.

To obtain the rate of CHF increase quantitatively, it is defined as follows:

$$\left(q''_{MV} - q''_{NMV}\right)/\, q''_{NMV} \times 100$$

The CHF performances are compared in Fig. 3 along with the data belong to the PWR operating conditions; a pressure of 2000~3000 kPa and a mass flux of 1500~3000 kg/m^{2}s. The average of the CHF increases for the hybrid mixing grids for 20 data is 18.2% higher than that for the no vane grids. While the average of the CHF increases for the split mixing vane grids for 20 data is 14.5% higher than that for the no vane grids. Thus, the CHF performance of the hybrid mixing vane grids is higher by about 4% than that of the split mixing vane grids.

4. Conclusion

Experimental investigations were carried out with 5x5 rod bundles in the FTHEL at KAERI to estimate the CHF performances of the hybrid mixing vane grid, relative to a no vane grid and a split mixing vane grid. From the results, the following were observed:

- The mixing vanes on the spacer grid increased the CHF as the mass flux increased. The hybrid vane grid showed a apparently better CHF performance above a mass flux of 1,500 kg/ m^{2}s
- Near the normal PWR operating conditions, the CHF performance of the hybrid mixing vane grid is superior by about 16.4% to that of the no mixing vane grid and by about 4% to that of the split mixing vane grid under a longer grid span than the actual one of the 16x16 fuel bundle for the KSNP.

Consequently, it was found that the hybrid mixing vanes had an excellent CHF performance.

Acknowledgment

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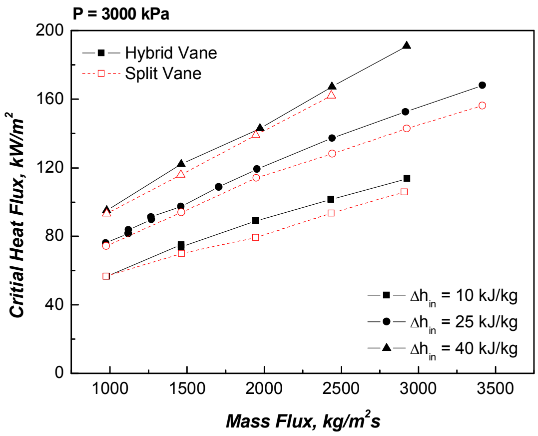

Fig. 2 Comparisons of the CHF (P=3000 kPa)

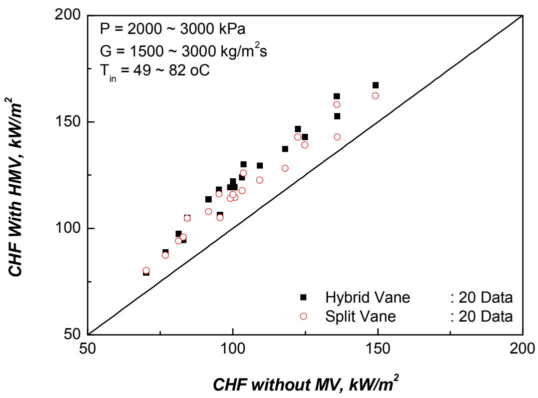

Fig. 3 Comparisons of the CHF Performances