

CHF Performance of Hybrid Mixing Vane Grid on 5x5 Rod Bundle

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Abstract

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. 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. 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. It's called a Hybrid Mixing Vane, 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 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). The test matrix sufficiently covers the PWR operating conditions for water equivalence.

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 OPR-1000.

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 °C higher than the saturation temperature.

The experiments were performed in ranges of the inlet pressure, $P_{in} = 2000\sim 3000$ kPa, mass flux, $G = 1000\sim 3000$ kg/m²s, and inlet subcooling, $\Delta h_{in} = 10\sim 55$ kJ/kg, which simulate the PWR operating conditions for a water equivalence through a fluid-to-fluid modeling.

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.

As a result, at a low mass flux of 1000 kg/m²s, the differences in the CHF between the hybrid and the split vane grids are fairly small, as expected. But above a mass flux of 1500 kg/m²s 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/m²s and an inlet subcooling of $\Delta h_{in} = 25$ kJ/kg, the hybrid mixing vane grid shows a higher CHF of about 6.3% than the split mixing vane grid.

The CHF performances are compared with the data belong to the PWR operating conditions; a pressure of 2000~3000 kPa and a mass flux of 1500~3000 kg/m²s. 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.

Consequently, the CHF performance of the hybrid mixing vane grid is superior by about 4% to that of the split mixing vane grid near the normal PWR operating conditions even under longer grid span than usual.

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