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Estimation of the Thermal Diffusion Coefficient for the Hybrid Mixing Vane

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1. Introduction

A fuel assembly of the nuclear reactors includes the unheated rods to insert control rods or in-core detectors as well as to replace damaged fuel rods during the operation. These unheated rods may change a radial power distribution and eventually affect on the local thermal hydraulic properties in subchannels and critical heat flux (CHF). Thus, the effects of the unheated rods should be taken account in the design of reactors. However, few experimental results for local thermal hydraulic properties which are mainly affected by the unheated rods are obtained so far.

The spacer grids with mixing vanes have been adopted to improve the homogeneity of local properties. Recently, Hybrid Mixing Vane was developed by KAERI [1], which comprises two types of vanes; primary vanes for a cross flow between subchannels, and secondary vanes for a swirl flow within the subchannels. The geometry of mixing vane influences significantly on the thermal hydraulic phenomena between the subchannel [2].

Among the mathematical parameters to describe the interchannel interactions, the thermal diffusion coefficient (TDC) has been used in the subchnnel analysis code such as the MATRA to simulate the thermal hydraulic condition of the inner-part of nuclear reactor. In general, the subchannel analysis code adopts the TDC to simplify the interaction between the adjacent subchannels. The TDC is highly affected by the geometry of the mixing vane and axial distances from spacer grids. Especially, turbulent mixing parameter is determined considering the mixing performance of the spacer grid; it generally has the range 0.005 ~ 0.05.

In this study, local fluid temperatures in the subchannel are measured from the experiment using the FTHEL (Freon Thermal Hydraulics Experimental Loop) [2] facility and estimated from MATRA code analyses varying the turbulent mixing parameters. From this estimation, the best optimized turbulent mixing parameter is proposed for the Hybrid Mixing Vane.

2. Experiment for Fluid Temperature

The FTHEL facility at KAERI has the components such as main circulation pumps, pre-heaters, test-section, DC power supply, condensers and coolers. HFC-134a is used as working fluid and heated through a test-section in which 5×5 rod bundle is axial-uniformly heated by DC power supply. In the heated zone, the rod bundle is supported by three spacer grids with Hybrid Mixing Vane. The specification of the rod bundle is listed in Table 1.

Table 1. Specifications of 5x5 rod bundle

Parameter	Value
Total number of heater rods	20
Total number of non-heating rods	5
Rod pitch (mm) / Rod diameter (mm)	12.85 / 9.5
Rod to wall gap (mm)	3.25
Heated length (mm)	2000
Distance between spacer grid (mm)	564
Flow area (mm^2)	2762.98
Heated equivalent diameter (mm)	18.07
Axial power distribution	Uniform
Radial power distribution	Non-uniform
Mixing vane	Hybrid
Working fluid	HFC-134a

Figure 1 shows the cross section of the rod bundle with heated and unheated rods, which has the symmetrical power distribution approximately. Five unheated rods are located at the central region of the rod bundle, which results in five categorized subchannels considering the power factors of surrounding rods; hot (subchannel number 4, 9, 12), middle (3, 10, 11), cold (6, 7), corner (2, 13) and side(1, 5, 8, 14). To measure the fluid temperature flowing through the subchannel, special-graded K-type thermocouples (error bound ±0.3 ^oC) are installed in the specific subchannel as shown in Figure 1.

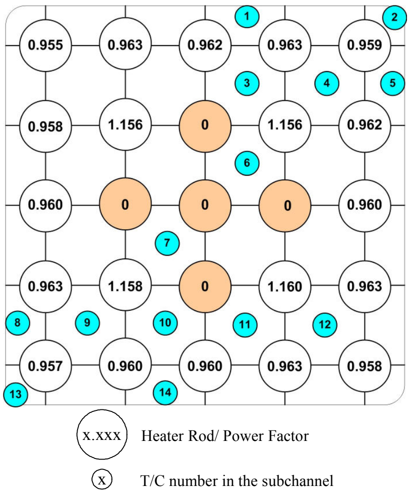

Figure 1. Arrangement of unheated rod and thermocouple for TDC measurement

Experiments are carried out in the ranges of an outlet pressure from 2000 to 3500 kPa, a mass flux from 600 to 2500 kg/m^{2}s, an inlet subcooling of 50 kJ/kg, and a total power of 100 and 150 kW. Based on the categorized subchannels, total 110 data points are obtained and analyzed in this study.

3. Results and Discussion

Figure 2 shows the typical fluid temperature distribution in the subchannel. As generally known, the subchannel temperature increases with increasing the system pressure and with decreasing the mass flux. The temperature difference between subchannels is notable between hot and cold subchannels and the temperature difference increases with increasing the average fluid temperature. Therefore, simple assumption can be made that turbulent mixing effect by mixing vane is maximized under lower pressure and higher mass flow rate.

Based on the measured average fluid temperature in the categorized subchannel, the measured subchannel fluid temperatures are compared with the predicted temperature by MATRA code. MATRA code analyses were performed by varying the turbulent mixing parameter (β). In this study, the best optimized value of β was found to be 0.02 by considering prediction statistics, i.e., average and standard deviations of the differences between the experimental results and code calculations as shown in Figure 3. Using the best optimized value of β as 0.02, the MATRA predicts the test results of the fluid temperature within ±1.0 % of error as shown in Figure 4.

4. Conclusion

Experiments have been performed to determine the thermal diffusion coefficient in the 5×5 rod bundle with 5 unheated rods which are supported by Hybrid Mixing Vane. In this study, HFC-134a fluid was used as working fluid and the fluid temperature were measured in the important subchannels. To determine the TDC value, the measured fluid temperatures were compared with the predicted values obtained from the MATRA code. The best optimized value of β was found to be 0.02 by considering prediction statistics, i.e., average and standard deviations of the differences between the experimental results and code calculations. Using the best optimized value of β as 0.02, the MATRA code predicts the test results of the fluid temperature within ±1.0 % of error.

Acknowledgment

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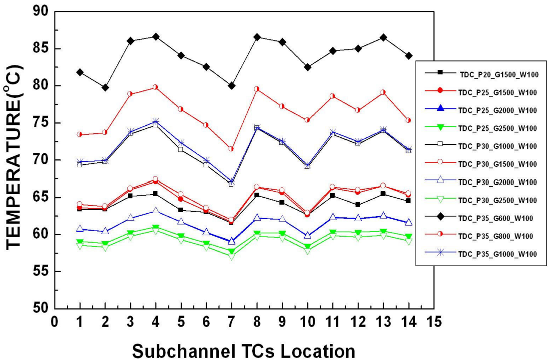

Figure 2. Temperature distribution in the subchannels

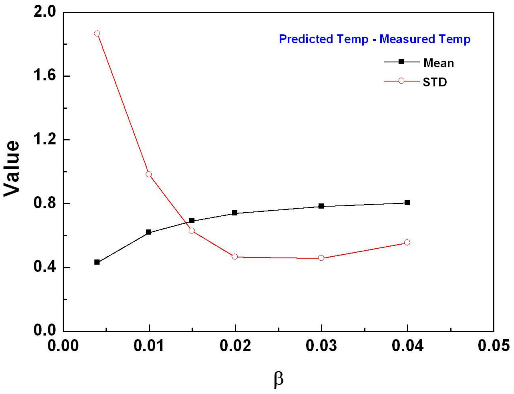

Figure 3. Statistics against the turbulent mixing parameter

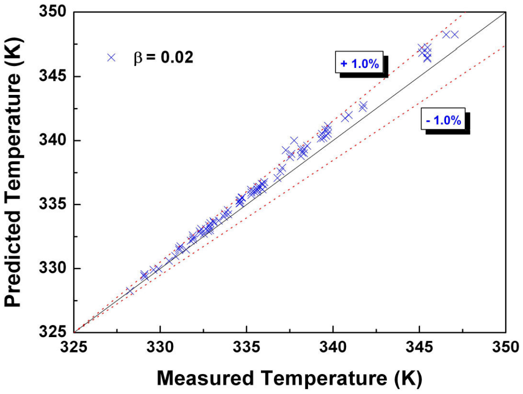

Figure 4. Comparison of the subchannel temperatures between the measurement and MATRA's prediction