Sensitivity Study of Regional TDC in MATRA-S code Using PSBT Benchmark Exercise

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1. Introduction

In the sub-channel analysis code, the modeling of interchannel exchanges between adjacent sub-channels expressed as diversion cross flow, turbulent mixing and so on. The turbulent mixing in MATRA-S code is considered as TDC(β : thermal diffusion coefficient). The TDC becomes different according to the bundle, grid type, mixing vane, and so on. Generally, the thermal mixing test is conducted to optimize the TDC. In the OECD/NRC PSBT benchmark[1], the thermal mixing test was conducted and the optimized TDC was analyzed using MATRA-S code[2]. It was shown that the exit temperature distribution of MATRA-S code was different from an experimental result even though the optimized TDC was applied to the code. In this study, concept of the regional TDC was introduced and sensitivity analysis of the regional TDC was presented.

2. Methods and Results

2.1 Thermal Diffusion Coefficient

In MATRA-S code, turbulent mixing flow rate per unit length from sub-channel, I, to adjacent sub-channel, J, is defined as:

$$w'_{IJ} = \beta \cdot s_{IJ} \cdot G_{avg}$$

, where s_{IJ} is the length of joint between sub-channel I and J, and G_{avg} is an average mass flux between two channels. β is TDC and is optimized by experiments. That is, the TDC is determined for errors of channel exit temperature between experiments and calculation and to be minimized. The thermal mixing test is conducted in the bundle consisted of two temperature regions as adjusting rod power.

In the previous work[2], it was shown that the temperature distributions of MATRA-S code at the exit were divided by hot and cold region and the mixing occurred from hot region to cold region, symmetrically. In MATRA-S code, the TDC was considered as constant, so that it looks like the thermal mixing occurred between only hot and cold region. However, the experimental results showed that the thermal mixing occurred in all regions of the bundle because of mixing vane. Due to the mixing vane, the cross flow in the bundle becomes vigorous. MATRA-S code considers the pressure drop by the mixing vane grid but the cross flow generated by the mixing vane is not considered. The thermal mixing effect of the cross flow by the mixing vane as applying the regional TDC, not constant value, can be induced.

2.2 Regional TDC Modeling

Sub-channels are grouped into four regions (HH, HC, CH, HH) and 8-TDC values ($\beta_1 \sim \beta_8$) are defined as shown in Fig. 1. The sub-channels can be divided into HOT and COLD region induced by the rod power distribution of the mixing test. The experimental result shows that two regions can be formed in each region due to the cross flow generated by mixing vane. Therefore, the sub-channels in HOT region can be divided into HH and HC region. The sub-channels in COLD region can be grouped into CH and CC region as shown in Fig.1, also.

The turbulent mixing between adjacent sub-channels was modeled as the each region had a different TDC value. The TDC value at the interface of each region was defined as an average TDC of two adjacent regions. Therefore, the TDCs at the interface are defined as followings:

$$\beta_5 = (\beta_1 + \beta_2)/2.0 \, , \, \beta_6 = (\beta_1 + \beta_3)/2.0$$
$$\beta_7 = (\beta_3 + \beta_4)/2.0 \, , \, \beta_8 = (\beta_2 + \beta_4)/2.0$$

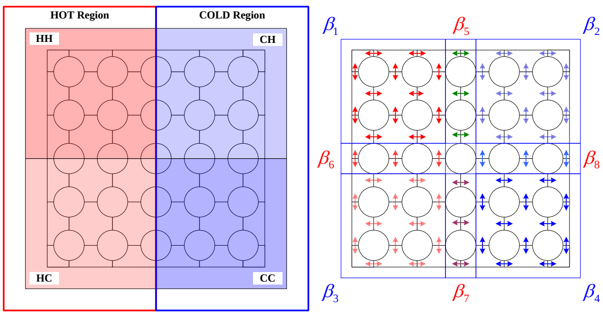

Fig. 1. 4-regions of bundle and regional TDC modeling

2.3 Regional Temperature

The regional temperature transition of PSBT A1-1237 was shown in Fig. 2. as increasing TDC value. At this time, the regions are identical with Fig.1. The temperature of HOT region decreases and the temperature of COLD region increases as the TDC value is increasing because the thermal mixing increases.

Besides, in the experiments, the temperature gradient exists inside HOT or COLD region. However, the temperature gradient between HH and HC or CH and

CC is still not shown in the calculation result. This trend is maintained as increasing the TDC value.

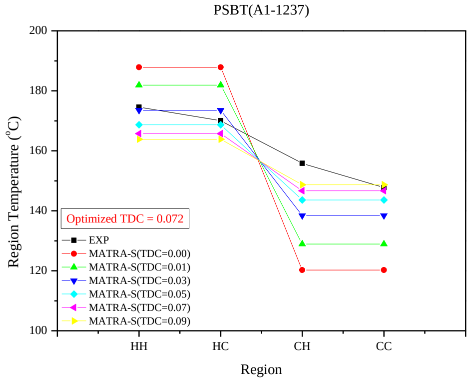

Fig. 2. Regional temperature change as increasing TDC value (PSBT A1-1237)

2.4 Sensitivity Analysis of Regional TDC

Sensitivity test on the regional TDC was achieved and one of the test matrices was shown in Table I when the variable is β_1. The TDC value in HH region, β_1, was increased from 0.010 to 0.060. At this time, β_5 and β_6 were simultaneously increased because β_1 is coupled with β_5 and β_6. The calculation result of the regional temperature was shown and the variable TDC region was figured out as shown in Fig. 3. The based case was shaded with red color in Table I ($\beta_1 = \beta_4 = 0.01$, $\beta_2 = \beta_3 = 0.06$). It is shown that the temperature gradient was formed when the regional TDC was used, not a constant TDC. The temperature of HH region was decreased as β_1 was increased. The temperature of HC and CH region, which was coupled with HH region, was decreased and increased, respectively. The sensitivity trends of β_4 was similar with that of β_1. The magnitude of the regional temperature was decreased as the regional TDC was increased. The TDC in the interface of regions affected adjacent region. That is, β_5 and β_7 affected on HH and CH region, and HC and CC region, respectively. However, it was shown that the effect of β_6 and β_8 was minute. It is the reason why the enthalpy differences between HH and HC or CH and CC is smaller than those between HH and CH or HC and CC, relatively.

3. Conclusions

The concept of the regional TDC was proposed to consider the effects of cross flow induced by the mixing vane, not pure thermal diffusion. The simple model to apply the regional TDC was presented and the sensitivity of the regional TDC was shown. It is expected that the detail model of regional TDC such as a local TDC of each sub-channel will improve the capacity of MATRA-S code.

Table I: Example-Sensitivity Test Matrix (variable: β_1 case)

TDC1	TDC2	TDC3	TDC4	TDC5	TDC6	TDC7	TDC8
0.010	0.060	0.060	0.010	0.035	0.035	0.035	0.035
0.020	0.060	0.060	0.010	0.040	0.040	0.035	0.035
0.030	0.060	0.060	0.010	0.045	0.045	0.035	0.035
0.040	0.060	0.060	0.010	0.050	0.050	0.035	0.035
0.050	0.060	0.060	0.010	0.055	0.055	0.035	0.035
0.060	0.060	0.060	0.010	0.060	0.060	0.035	0.035

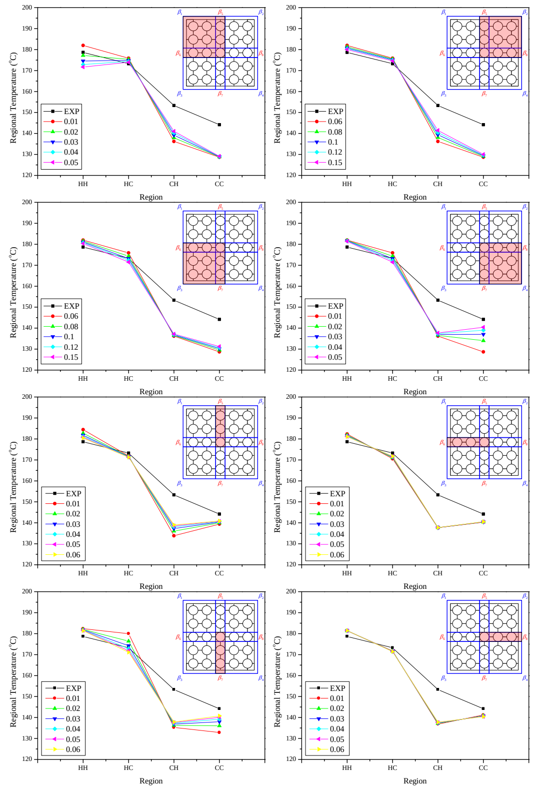

Fig. 3. Sensitivity of regional temperature as regional TDC

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[1] A. Rubin, et. al., OECD/NRC Benchmark Based on NUPEC PWR Subchannel and Bundle Tests (PSBT) Volume I: Experimental Database and Final Problem Specifications, NEA/NSC/DOC(2010)1, 2010.

[2] D. H. Hwang, et. al., Analysis of PSBT Benchmark Exercises for Void Distribution and DNB Using a Subchannel Code MATRA, The 14th International Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH-14, Toronto, Ontario, Canada, September 25-30, 2011