Validation of CUPID for Subchannel Scale Analysis with PSBT Thermal Mixing Test

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1. Introduction

For high fidelity safety analysis using thermal-hydraulic simulation tool, subchannel scale analysis could be a feasible solution as it can provide better spatial resolution than system scale analysis in reasonable calculation time for whole reactor core pin-by-pin analysis.

CUPID [1] is in-house code developed by KAERI(Korea Atomic Energy Research Institute). Its subchannel scale analysis capability has been improved in our previous works [2]. Not only basic models of a subchannel analysis code such as turbulent mixing and void drift models, but also spacer grid and mixing vane models were implemented in recent works [3].

In this study, the grid directed cross flow model caused by the mixing vane implemented in CUPID would be validated against the PSBT thermal mixing benchmark [4].

2. Grid Directed Cross Flow Model in CUPID

In previous work [3], the mixing vane directed cross flow model was implemented in CUPID. This model represents the lateral momentum caused by mixing vane. The effects of mixing vane is considered by lateral convection factor of which meaning is the ratio between the axial velocity to the lateral velocity created by the mixing vane. This factor needs to be determine by CFD calculation. In this study, 0.27 is used for lateral convection factor based on the CFD calculation result of Blyth [5].

According to this model, the terms below were implemented in the liquid mass, momentum, and energy conservation equations,

$$
\begin{aligned}
M_e &= f u_l \rho_l A \\
M_k &= f^2 u_l \rho_l A \times u_l \qquad (1) \\
M_h &= f u_l \rho_l A \times h_l
\end{aligned}
$$

where M_e, M_k, M_h : mass, momentum and energy transfer due to mixing vane model,
f : Lateral convection factor,
u_l : Axial liquid velocity,
A : Flow area

3. PSBT Test Facility

PSBT stands for NUPEC PWR Subchannel and Bundle Tests, which benchmark is provided by OECD/NRC [4]. For steady-state bundle benchmark, the single assembly with 5x5 heated rods of which active heating length was 3658mm were used. The outer diameter of the rod is 9.5mm and inner length of flow channel is 64.9mm. Various tests were performed in the PSBT benchmark and in this study, the thermal mixing test data were analyzed focusing on the mixing caused by mixing vane. This test was a single phase experiment and the outlet temperature data were provided for the validation. Test number 01-5343 was selected for validation. Fig. 1 shows the power distribution for each rods, in 01-5343 test.

1.00	1.00	0.25	0.25	0.25
1.00	1.00	1.00	0.25	0.25
1.00	1.00	0.25	0.25	0.25
1.00	1.00	1.00	0.25	0.25
1.00	1.00	0.25	0.25	0.25

Fig. 1. Power distribution of Test 01-5343

PSBT test facility has 17 spacer grids and on 7 of them, the mixing vanes were attached. There are three types of spacer grids, simple spacer grids, mixing vane spacer grids, and non-mixing vane spacer grids. The mixing vane spacer grid and simple spacer grid were alternatively located along the assembly. Simple spacer grid has shorter axial length than mixing vane spacer grid. At the top and bottom of the assembly, non-mixing vane spacer grids were installed, which has same shape with mixing vane spacer grid, but has no mixing vanes on it. The pressure loss coefficients for each types of spacer grid were provided by the experiment. In this study, the mixing vane directed cross flow model was implemented for each mixing vane spacer grid in order to simulate the mixing vane effect. The directions of lateral momentum generated by mixing vanes according to the configuration of the grid spacer for each gaps are illustrated in Fig. 2.

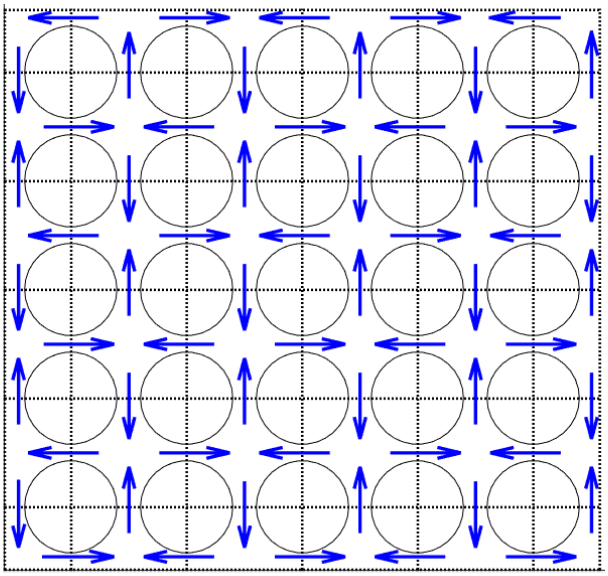

Fig. 2. Mixing vane direction for each gaps in PSBT

4. Calculation Results and Discussions

Fig. 3 shows the outlet temperature distribution from the experimental result of PSBT test 01-5343. According to Fig. 1, the left part of the assembly is supposed to have higher temperature than the right side. But in the experimental result, the highest temperature was observed at the top left corner of the assembly, while the lowest temperature at the bottom right corner. This result implies that the overall direction of the flow mixing caused by the vane is clockwise.

Fig. 4 shows the outlet temperature distribution from the CUPID calculation. Different from the experimental result, the highest temperature is located at the bottom left corner and the lowest temperature is located at the top right corner. In this calculation, coolant is mixed in counter-clockwise contrary to the experimental result.

According to Fig. 2, the mixing vane direction at the corner subchannels is counter-clockwise. Mixing vane directions in other subchannels are canceling each other, while corner subchannels are not. Therefore in the CUPID calculation, mixing vane effect in corner subchannels take dominant part in the entire coolant flow. Considering this situation, the lateral convection factor at the corner subchannels were reduced from 0.27 to 0.1 to investigate the change of the flow direction and Fig. 5 shows the CUPID calculation result with reduced value. After the modification, the highest temperature is located at the top left corner similar with the experimental result as shown in Fig. 5 and Fig. 6. Shows the stream before and after the modification of the corner subchannel's lateral convection factor. The change of the rotation direction was clearly displayed.

From the result, it was deduced that the lateral convection factor can vary depending on the subchannel types, i.e. center subchannel, side subchannel, and corner subchannel.

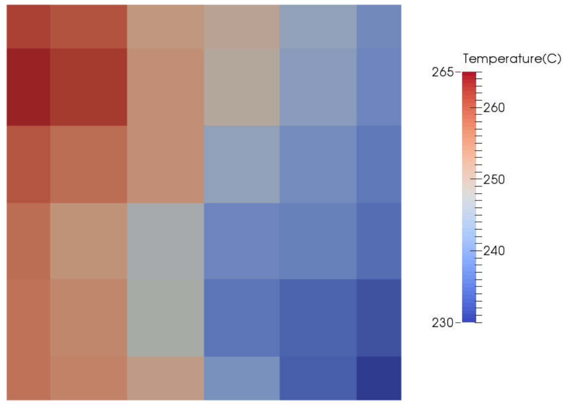

Fig. 3. Experimental result of outlet temperature of 01-5343 test

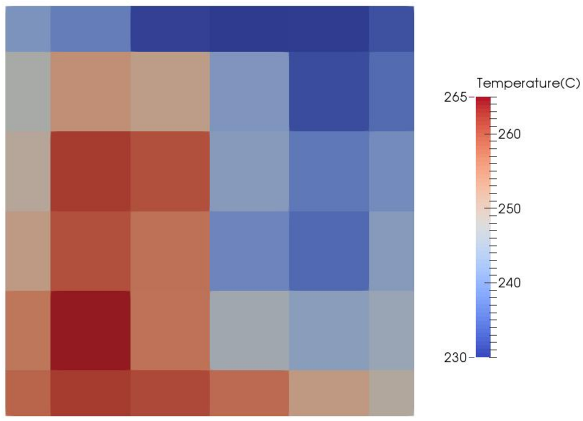

Fig. 4. CUPID calculation result of outlet temperature of 01-5343 test

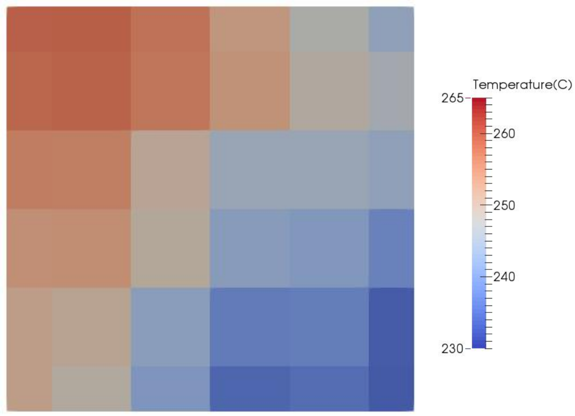

Fig. 5. CUPID calculation result of outlet temperature of 01-5343 test with reducing lateral convection factor at the corner

Fig. 7 shows the comparison between the experiment and calculation in Figs. 3 and 5, respectively. The temperature difference at each subchannel has in 5℃ error and it was concluded that further improvement is desired even though the rotation direction can be reproduced.

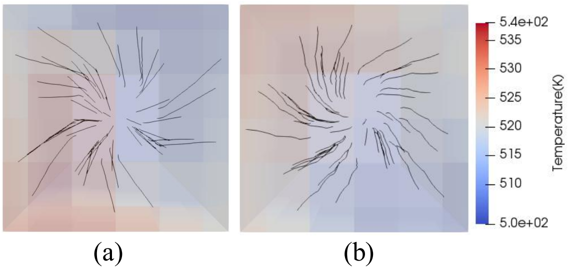

Fig. 6. Coolant streamline in CUPID calculation with (a) uniform lateral convection factor and (b) reducing lateral convection factor at corner

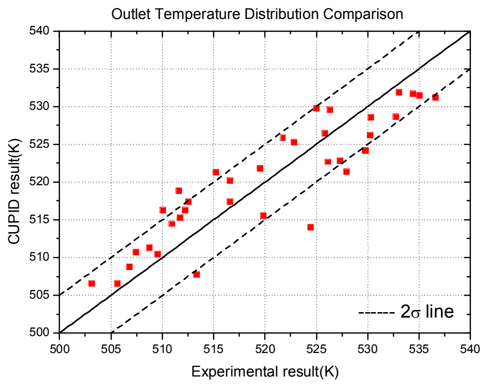

Fig. 7. Outlet temperature comparison between experiment and CUPID calculation

5. Conclusion

In the subchannel analysis module of CUPID code, the mixing vane grid directed cross flow model was implemented. In order to validate this model, PSBT thermal mixing test was analyzed. CUPID can well simulate the outlet temperature distribution, by modifying the lateral convection factor at the corner subchannel qualitatively.

For future work, more CFD calculation to derive the lateral convection factor is needed in order to apply optimized values into CUPID and improve the model's capability.

ACKNOWLEDGEMENT

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