Numerical Analysis for IFM Grid Effect on 5x5 Rods Bundle

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1. Introduction

Generally, the fuel assembly consists of fuel rods, bottom and top grids, spacer grids, mixing vane, etc. The mixing vane with spacer grid is used to increase the thermal mixing between subchannels and to increase CHF(Critical Heat Flux). IFM(Intermediate Flow Mixer) grids are used to induce lateral flow between adjacent channels and are well-known as improving CHF, also. A numerical analysis using CFD code(ANSYS CFX, version 12.1[1]) and subchannel code(MATRA-S[2]) was conducted to investigate the influence of IFM grid on the subchannel temperature in 5x5 rods bundle with and without the IFM grid, thermo-hydraulically. In this study, the quantitative improvement of the mixing effect of the IFM grid is presented from the results of CFX and MATRA-S code. Moreover, capacity of predicting subchannel temperature of MATRA-S code is compared with CFX result.

2. Analysis

In this section, the numerical methods applied to CFX and MATRA-S code are described and the results are summarized.

2.1 CFD analysis

The total length of rods bundle to calculate is 2000 mm and rod's diameter and pitch are 9.5 and 12.6 mm, respectively. The distance from the rod to wall is 2.855 mm and an arrangement of 25 rods is 5x5 square. The mixing vane and IFM grids were simplified as omitting the dimples and springs.

The simplified mixing vane and IFM grid are depicted as shown in Fig. 1. As shown in Fig. 1, 3 MV and 2 IFM grids were considered. The IFM#2 and IFM#1 were located between MV#2 and MV#1, MV#1 and EHL(End of Heated Length), respectively.

The computational domains for the upper and lower parts of the mixing vanes were generated by applying the hexagonal sweep method while tetrahedron meshes were applied to the mixing vane region. The computational geometry with and without the IFM grids, consisted of about 6,100,000 tetrahedra and 4,100,000 hexahedron, 3,600,000 tetrahedra and 4,100,000 hexahedron, respectively. The SST model[3] was adapted to the turbulent model, which is well-known as showing good-agreements of predicting pressure drops even if numerical meshes are not fine. It is used that the RMS residual is under 10^{-6} as the convergence criteria. The operating conditions of working fluid are tabulated as shown in Table I. The different radial power peaking was considered to induce the thermal mixing between subchannels. Therefore, the interior rods (rod# 7~9, 12~14, 17~19) have higher heat flux, 625.0 kW/m^2, than the peripheral rods whose heat flux is 429.5 kW/m^2. The axially uniform heat flux was applied to all rods.

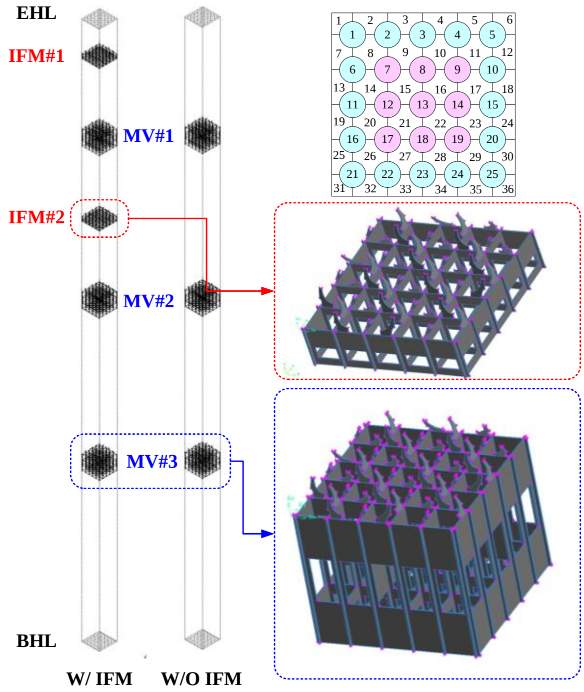

Fig. 1. Simplified mixing vane and IFM grid for CFD analysis

Table I: Operation and boundary conditions

Operation Conditions			
Exit Pressure		15.571	MPa
Inlet Temperature		280.208	°C
Inlet Mass Flux		1002.251	kg/m^{2}s
Axial Power Peaking		Uniform	
Radial Power Peaking		0.859/1.250(Side/Interior)	
Boundary Conditions			
Inlet	Mass Flow Rate	2.538	kg/s
Outlet	Relative Pressure	0.0	Pa
Wall	Constant Heat Flux	429500/625000	W/m^2

2.2 Subchannel analysis

The MATRA-S code was adapted to investigate the thermal mixing of the IFM grid in subchannel code. In the MATRA-S code, the turbulent mixing of single phase is considered as Eq. (1).

$$w' = \beta s \overline{G} \tag{1}$$

where, β is TDC(Thermal Diffusion Coefficient). s and $\overline{G}$ mean the gap size and mean mass velocity between adjacent subchannels, respectively. From Eq.(1), it is known that the thermal mixing is more vigorous when the TDC has a higher value. This value is different according to rods bundle types and grid design, etc. so that it has obtained through the mixing test, generally.

The mixing effect of the IFM grid could be investigated by determining an optimized TDC of rods bundle with and without the IFM grid. The optimized TDC can be defined as the value to minimize RMS error of normalized temperature difference between the CFX and MATRA-S code at the exit of bundle. At this time, RMS error is defined as Eq. (2).

$$RMS \equiv \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(\frac{\Delta T_i^{CFX}}{\Delta T_{AVG}^{CFX}} - \frac{\Delta T_i^{MATRA}}{\Delta T_{AVG}^{MATRA}}\right)^2} \tag{2}$$

where,

$\Delta T_{AVG}^{CFX} = T_{out}^{CFX} - T_{in}^{CFX}$,

$\Delta T_{AVG}^{MATRA} = T_{out}^{MATRA} - T_{in}^{MATRA}$,

$T_{in}^{CFX} = T_{in}^{MATRA}$,

$\Delta T_i^{CFX} = (T_i - T_{in})^{CFX}$,

$\Delta T_i^{MATRA} = (T_i - T_{in})^{MATRA}$

and the subscript *i*, *in*, and *out* mean the subchannel number, inlet, and outlet, respectively. The calculation of MATRA-S code was iterated in order to obtain the optimized TDC until the RMS error of the exit temperature satisfied convergence criteria.

Moreover, $f = 0.18\,\mathrm{Re}^{-0.2}$ was used as single phase turbulent friction factor(f), and the pressure loss coefficient of MV and IFM grid was applied to 1.243 and 0.749, respectively.

2.3 Analysis results

The axial distribution of maximum and minimum subchannel temperature in CFD calculation with and without IFM grid was shown in Fig. 2. As shown in Fig.2, the maximum subchannel temperature was decreased when the IFM grids were used. That is, the local and subchannel temperature at the exit were decreased by about 2.8^{o}C and 2.1^{o}C, respectively. These differences correspond to 5.5% and 4.1% of total temperature rising ($T_{out} - T_{in} \cong 51.3\,^o$C).

The variation of subchannel temperature in IFM grid region is shown in Fig. 3. Figure 3 shows that the vigorous mixing occurs after going throughout IFM grid. The optimized TDC of the MATRA-S code was evaluated as 0.064 and 0.081 for w/o and w/ IFM grids, respectively. This means that the thermal mixing and lateral flow was increased when the IFM grids were considered.

Besides, the comparison of subchannel temperature at the exit between CFX and MATRA-S code applied to the optimized TDC was shown in Fig. 4. Figure 4 shows that the MATRA-S code predicts the subchannel temperature well.

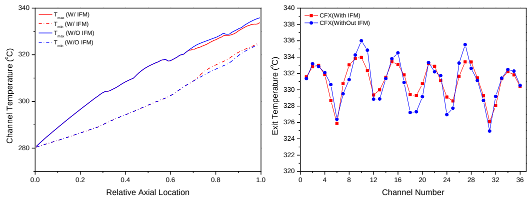

Fig. 2. Subchannel temperature w/ and w/o IFM grid (a. axial distribution, b. exit distribution)

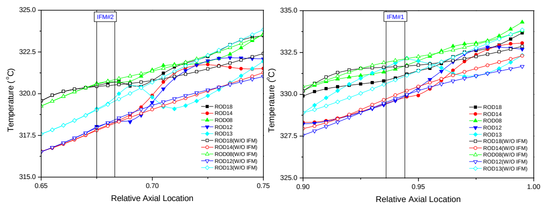

Fig. 3. Thermal mixing at IFM grid (a. IFM#2, b. IFM#1)

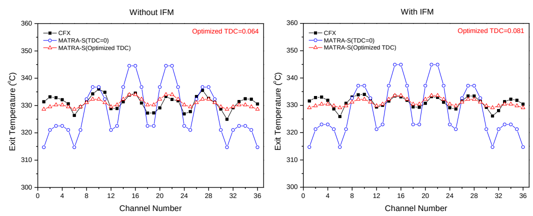

Fig. 4. Comparison of exit temperature between CFX and MATRA-S code (a. w/o IFM grid, b. w/ IFM grid)

3. Conclusions

As the IFM grid was used, the local and subchannel temperature at the exit was decreased by 5.5% and 4.1% of total temperature rising, respectively. The optimized TDC value was increased from 0.064 to 0.081 due to the induced and increased mixing by the IFM grid, also. These imply that the CHF will be improved by applying to IFM grid. Moreover, it was shown that the MATRA-S code predicts the subchannel temperature well.

REFERENCES

[1] ANSYS CFX Release 12.1, 2009.
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[3] D.C. Wilcox, Turbulence Modeling for CFD, DWC industries, La Canada, 1993.