Case Study of MATRA-S for PNL 7x7 Rod Bundle Blockage - II. CFD Analysis

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1. Introduction

The MATRA-S[1] is one of the subchannel analysis codes, which has been developing for a system integrated modular advanced reactor (SMART). As one of the validation of MATRA-S code, the PNL 7x7 blockage flow test[2] was selected and calculated. The PNL 7x7 blockage test was conducted to investigate the turbulent phenomena near the blockage when the flow area was decreased.

The flow blockage test can simulate the swelling and ballooning of the fuel rods in the accident such as LOCA. The experiments were simulated using a sleeve to block the flow channel and the ratios of the narrowed channel area were 70 and 90%. In this study, the 70% blockage test was used to validate MATRA-S code. Moreover, CFX code was used to compare the result of MATRS-S code.

2. Subchannel Analysis

MATRA-S code was used to calculate the PNL 7x7 blockage flow condition. The change of the channel area caused by the sleeve in the experiment was considered as adjusting the gab size between subchannels and flow area.

The nonuniform axial-node was used to reflect the various flow areas, sufficiently. That is, the dense axial nodes were used near the sleeve and the axial nodes were sparse receding from the blockage region. Figure 1 shows the used subchannel model and an axial distribution of the nonuniform nodes in this study.

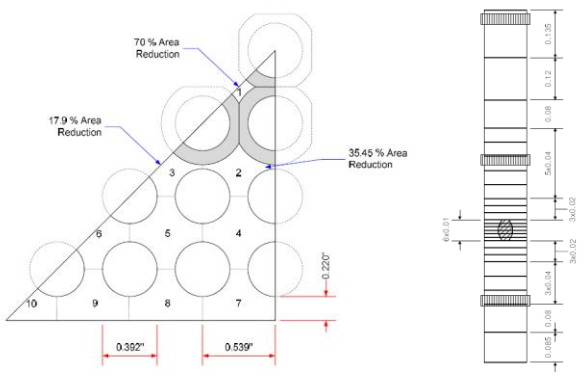


Fig. 1. Subchannel model of MATRA-S: (a) Subchannel dimension(unit: mm) (b) Nonuniform axial nodes(relative length)

As shown in Fig. 1, 1/8 of 7x7 bundle was modeled and 10 subchannels consisted of a cross section. The length of the calculating domain is 50 inches and the flow are start to narrow at 17.25 inches from an inlet. The values in Fig 1.(b) mean relative length to input at the MATRA-S code.

The grids to support and maintain gab between rods were used in the experiments. However, the grids were not considered in this subchannel analysis to simplify the calculation domain in CFD analysis.

The single phase turbulent friction factor, f used Eq.(1) to consider square rod array.

$$f = 0.34\,\mathrm{Re}^{-0.25} \qquad (1)$$

3. CFD Analysis

To compare the result of MATRA-S code with that of CFD code, ANSYS CFX[3] was used. The 1/4 bundle was considered as numerical domain. The hexahedrons about 2,600,000 consist of the whole numerical domain. The meshes were generated using the Cooper scheme in Gambit 2.23. The body was split with several sub-bodies to generate the whole body to be hexahedral. The boundary layers were used to obtain more accurate results at the wall. Face meshes were generated and then volume meshes were generated as projecting meshed face along the wall so the boundary layers were maintained from the inlet to outlet. Figure 2. shows the geometry and the mesh used in this study.

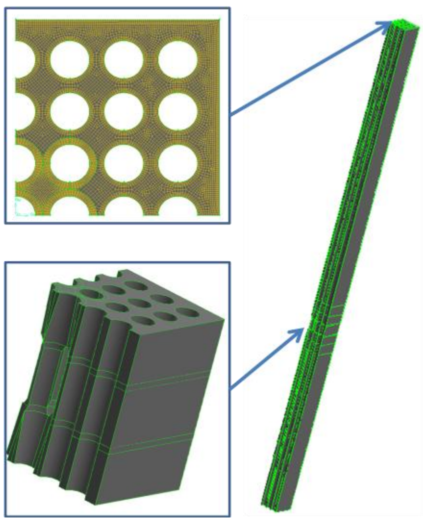


Fig. 2. Hexahedrons for calculating 1/4 bundle of PNL 7x7

The fine axial nodes were concentrated on the front and the rear of the blockage including the blockage, where the complex flow field is expected. That is, the sub-bodies positioned within 1 inch at the start and end position of blockage had fine volume mesh also.

The inlet is set to be a uniform velocity boundary and the outlet to be a pressure boundary condition for the relative pressure to be 0. Moreover, the symmetry boundary is used to consider the symmetry of the bundle and the remains used the wall boundary condition.

The shear stress transport based on the k-ω model of Wilcox [3,4] is designed to an accurate prediction of the onset and the amount of flow separation under adverse pressure gradients by the inclusion of transport effects into the formulation of the eddy viscosity. The high resolution scheme is used to calculate the turbulence. The convergence criterion is set to be 10^{-6} RMS residual.

4. Results

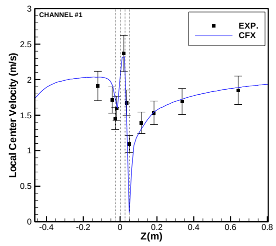
The channel average velocity of CFX result was compared with the channel velocity of MATRA-S code. Figure 3. shows the results of MATRA-S and CFX. The axial location of the blockage is from -0.0254 mm to 0.0508 mm. The square symbol means the measured local velocity in the PNL experiment and the solid line means that of CFX calculation in Fig. 3-(a). The experiments showed that the local velocity at the centerline of the channel 1 had sudden changes in the blockage region as shown in Fig. 3-(a). Those changes were showed in CFX results. The quantitative comparison of results between experiments and numerical analysis is difficult, because the grids were not considered in the numerical as mentioned in chapter 2. However, the trend of drastic changes at the centerline of channel 1 of the numerical results accords with experiments.

In case of CFX, the velocity was area-averaged at the region according to each channel of MATRA-S code as shown in Fig. 1. The results are depicted in Fig. 3-(b)~(d) as regards subchannel 1~3 of MATRA-S code, where the channel average velocity ratio means the ratio of the area-averaged to an inlet averaged velocity. The red-square symbol and blue-triangle symbol mean the channel velocity of MATRA-S and CFX, respectively.

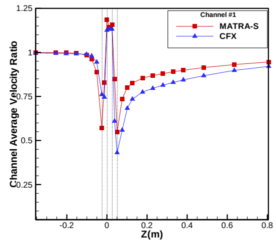
From the results, it is noted that the channel velocity of the MATRA-S is accord with the area-averaged velocity of CFX, as well except for the latter part of the blockage in case of the channel 1. The channel velocity of others showed the coincidence between MATRA-S and CFX even thought the figures are not included in this paper.

The velocity trends of drastically decreasing, increasing and recovering at the region of the block are same and the differences between MATRA-S and CFX are small.

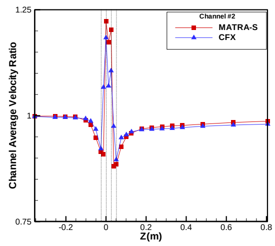
It is noted that the MATRA-S estimates the axial and radial velocity profile as well and might be applied to an analysis of accompanying complex flow pattern applying axially nonuniform nodes.



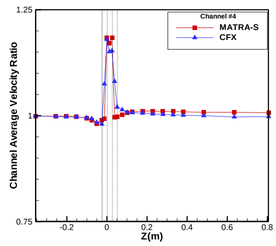
(a) Local velocity of Channel 1



(b) Average velocity of Channel 1



(c) Average velocity of Channel 2



(d) Average velocity of Channel 3

Fig. 3. CFD Analysis results: (a) Local velocity at centerline of channel 1, (b)~(d) Area-averaged velocity ratio channel 1~3

5. Conclusions

The numerical analysis on the PNL 7x7 blockage flow test(70%) to validate the MATRA-S code achieved using CFX-code. The channel velocity of MATRA-S was agreed with the area-averaged velocity of CFX according to each channel area.

Moreover, MATRA-S showed the capability to estimate the drastic velocity change caused by the variation of the flow area using the nonuniform axial nodes.

It is noted that MATRA-S can simulate the complex flow in spite of having the limitation of subchannel analysis code.

REFERENCES

[1] 서경원, “MATRA-S 소프트웨어 확인 및 검증보고서,” SMT-SVVR-TR10001, Rev. 01, 2010.
[2] J. M. Creer et al., Effects of Sleeve Blockages on Axial Velocity and Intensity of Turbulence in an Unheated 7x7 Rod Bundle, BNWL-1965, Battelle, 1976/01.
[3] ANSYS CFX Release 12.0, 2009.
[4] D.C. Wilcox, Turbulence Modeling for CFD, DWC industries, La Canada, 1993.