CFD Validation with a Multi-Block Experiment to Evaluate the Core Bypass Flow in VHTR

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1. Introduction

Core bypass flow of Very High Temperature Reactor (VHTR) is defined as the ineffective coolant which passes through the bypass gaps between the block columns and the crossflow gaps between the stacked blocks. This flows lead to the variation of the flow distribution in the core and affect the core thermal margin and the safety of VHTR. Therefore, bypass flow should be investigated and quantified. However, it is not a simple question, because the flow path of VHTR core is very complex. In particular, since dimensions of the bypass gap and the crossflow gap are of the order of few millimeters, it is very difficult to measure and to analyze the flow field at those gaps. Seoul National University (SNU) multi-block experiment [1] was carried out to evaluate the bypass flow distribution and the flow characteristics. The coolant flow rate through outlet of each block column was measured, but the local flow field was measured restrictively in the experiment. Instead, CFD analysis was carried out to investigate the local phenomena of the experiment. A commercial CFD code CFX-12 [2] was validated by comparing the simulation results and the experimental data.

2. CFD Validation with the Multi-Block Experiment

2.1 Constitution of Multi-Block Experiment Apparatus and Experimental Conditions

The multi-block experimental apparatus is an air test facility. This facility consists of a blower, a wind tunnel, test-section, measuring devices and data acquisition system. Figure 1 shows the cross-sectional of the test-section. Totally 11 blocks in a layer and 3 layers in a column are installed in the test section. Dimension of the test block of the experiment was scaled down to one-third of actual core block. Hence, the flat-to-flat width and the height of the hexagonal test block are 120 mm and 264 mm, respectively. 108 coolant holes of an actual fuel block were reduced to 6 holes while flow area ratio of the coolant holes to cross-section of a fuel block was preserved in the experiment. Respective thickness of the bypass gap and the crossflow gap are 2 mm. Bi-Directional Flow Tubes (BDFT) [3] were installed at the outlets of block columns to measure the flow distribution. Total 7 pressure taps along the bypass gap channel were installed at the side wall of the test-section.

In present study, the effect of the block arrangement was estimated by installing three kinds of block combinations of the fuel and reflector block. The experimental cases were distinguished as a number of fuel blocks as shown in Fig.1. Inlet mass flow rate of each case was adjusted so that the Reynolds number of the coolant hole within the fuel block could be same.

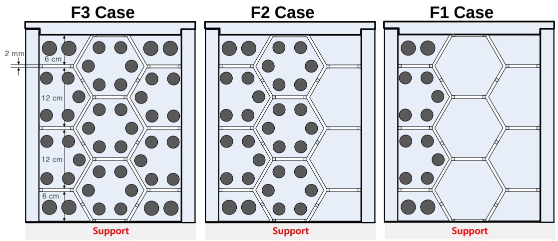

Fig. 1. Cross-sectional view of the test-section according to the block combination.

2.2 CFD Modeling and Boundary Conditions for the Multi-Block Experiment

CFD analysis using CFX-12 was performed to investigate a detailed flow field through the coolant holes and the gaps in the multi-block experimental apparatus. Also, the applicability of the CFD code was validated by comparing the simulation results with the experimental data. Figure 2 shows a computational domain and the mesh structure of the crossflow gap for F3 case. In present simulation, the unstructured hybrid mesh was used. Computational domains of F1, F2 and F3 cases were constructed by 1.49, 1.69 and 1.85 million cells, respectively.

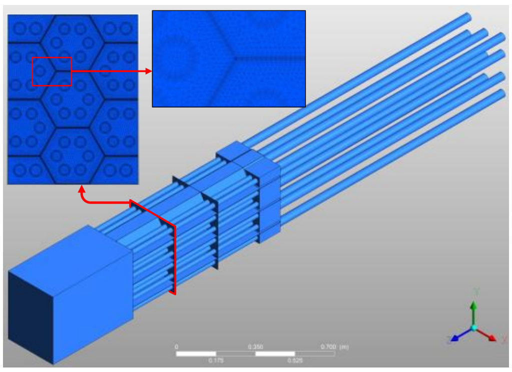

Fig. 2. Computational domain and the mesh structure at the crossflow gap for F3 case.

The working fluid is an air at the normal temperature and pressure. Shear Stress Transport (SST) model based on the Reynolds Averaged Navier-Stokes (RANS) equation is adopted for a turbulence closure in this simulation. And the upwind scheme was implemented for the convective terms.

3. Results and Discussions

3.1 CFD Validation of Flow and Pressure Distribution

Figure 3 shows a comparison of the CFD calculation results and the experimental result of the pressure drop along the bypass gap. As shown in this figure, the CFD analysis results show a good agreement with the experimental result. Pressure pattern of F2 case was similar to that of F3 case. However, in F1 case, the static pressure at the second crossflow gap shows different pattern. As shown in Fig.4, the pressure curve of F1 case rose slightly before it dropped sharply. Flow area of the bypass gap suddenly expands and contracts via the crossflow gap. In case of F2 and F3, the effect of sudden expansion of flow area is attenuated due to the crossflow from the adjacent fuel blocks. However, in contrast to F2 and F3 cases, the crossflow in F1 case flows from the fuel block to the crossflow gap between the reflector blocks without disturbance from the adjacent fuel block columns as shown in Figs. 5 and 6, respectively.

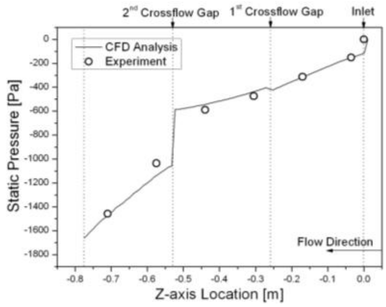

Fig. 3. Static pressure distribution of F3 case along the bypass gap between two fuel block columns.

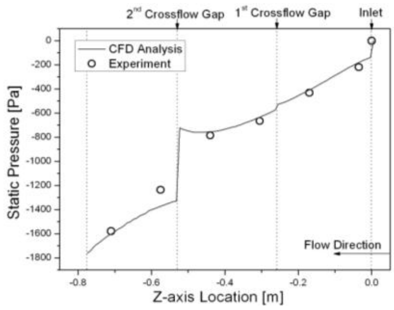

Fig. 4. Static pressure distribution of F1 case along the bypass gap between two fuel block columns.

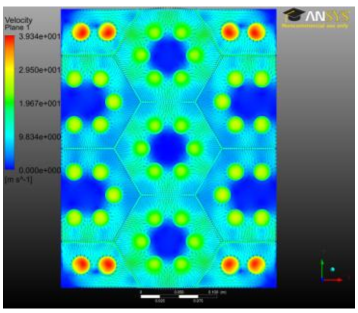

Fig. 5. Velocity distribution of F3 case at the second cross flow gap.

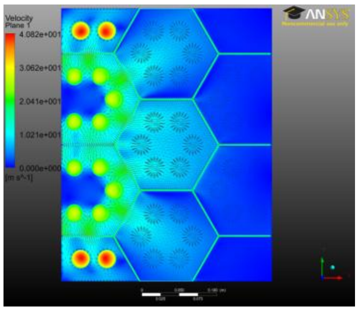

Fig. 6. Velocity distribution of F1 case at the second cross flow gap.

3.2 Prediction of Bypass Flow Rate

Bypass flow ratio is defined as the ratio of the bypass flow rate to the total flow rate in present study. The comparison results of the bypass flow ratio are tabulated in Table I. The maximum deviation between the CFD calculation and the experimental data was 7.77%. Considering the experimental and numerical errors, it can be found that CFD analysis results show a good agreement with the experimental data.

Table I: Comparison of Bypass Flow Ratio

	F3 case	F2 case	F1 case
Bypass flow rate [kg/s]	0.0760	0.0796	0.0708
Total flow rate [kg/s]	0.5628	0.4104	0.2443
Bypass flow ratio [%]	13.51	19.36	28.99
Bypass flow ratio [%] (Experiment)	14.5	21.03	29.75

4. Conclusions

SNU multi-block experiment was carried out to evaluate the bypass flow distribution and the effect of the crossflow. In addition, CFD analysis using CFX-12 was performed and its accuracy was validated by comparing with the experimental results. Consequently, it was found that the crossflow was influenced by the block combination. In conclusion, the CFD simulation results showed a good agreement with the experimental data and CFD analysis is enough accurate to be applied to analyze the actual reactor core.

REFERENCES

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