Preliminary Calculations of Bypass Flow Distribution in a Multi-Block Air Test

Min-Hwan Kim*, Nam-il Tak
Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, Rep. of Korea, 305-350
[*]Corresponding author: mhkim@kaeri.re.kr

1. Introduction

The development of a methodology for the bypass flow assessment in a prismatic VHTR (Very High Temperature Reactor) core has been conducted at KAERI. A preliminary estimation of variation of local bypass flow gap size between graphite blocks in the NHDD core were carried out.[1] With the predicted gap sizes, their influence on the bypass flow distribution and the core hot spot was assessed[2].

Due to the complexity of gap distributions, a system thermo-fluid analysis code is suggested as a tool for the core thermo-fluid analysis, the model and correlations of which should be validated. In order to generate data for validating the bypass flow analysis model, an experimental facility for a multi-block air test was constructed at Seoul National University (SNU).

This study is focused on the preliminary evaluation of flow distribution in the test section to understand how the flow is distributed and to help the selection of experimental case. A commercial CFD code, ANSYS CFX[3] is used for the analyses.

2. Computational Model

It is one of the advantages of the CFD analysis to provide a detailed flow distribution which is difficult to be measured in the SNU air test. Preliminary CFD analyses for the air test were performed to provide insight for determining the experimental conditions. The CFD model for the test section including the outlet region was prepared as shown in Fig. 1. The test section of the experiment consists of 4 layers and 7 columns of acryl blocks connected to transition layer and outlet pipes. Fuel and reflector block models are scaled to half size of real block. In the experiment, 108 coolant channels in the fuel block are reduced to 90 to secure space for pressure tube installation in the center.

Most of the air flow entering the inlet is supplied into the channel in the block and discharges to an open plenum through the outlet pipes. The other flow enters into bypass gaps between the blocks and exits at the bypass outlet. There are cross flow gaps between block layers, which connect coolant channels with bypass flow gaps.

The analysis cases considered are listed in Table 1. With two types of block arrangements (F7 and R2), three uniform BG (bypass gap) distributions (BG2, BG4 and BG6) and two non-uniform bypass gap distributions (BG6242, BG6240) were selected for assessing the effect on the bypass flow. The cross gap size was fixed at 2mm for all the cases except for the BG4 cases (F7-BG4-CG1, R2-BG4-CG1) in which the cross gap of 1mm was additionally included to estimate the effect of cross gap size on the bypass flow distribution.

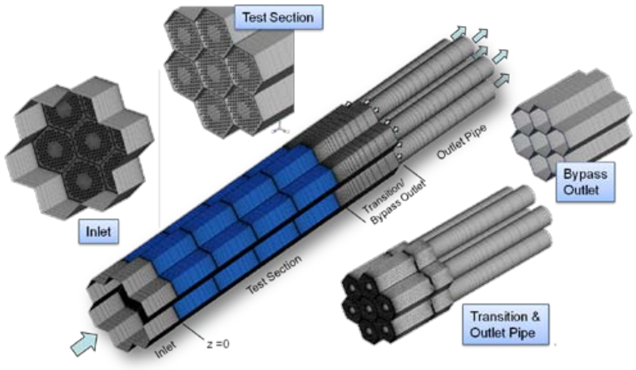
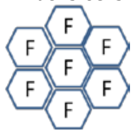


Fig. 1 CFD model

Table 1. Analysis cases for the pre-calculation of SNU air test

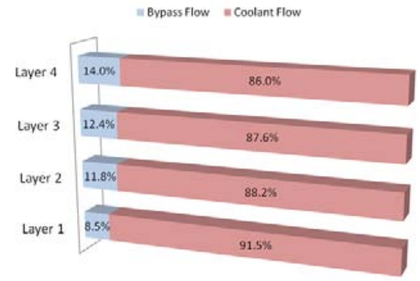
Cases	Arrangement of Block columns	Bypass Gap Size (mm)	Cross Gap Size (mm)
F7-BG2-CG2	7 fuel blocks 	2 (uniform)	2 (uniform)
F7-BG4-CG2		4 (uniform)	2 (uniform)
F7-BG4-CG1			1 (uniform)
F7-BG6-CG2		6 (uniform)	2 (uniform)
F7-BG6242-CG2		6, 2, 4, 2	
F7-BG6240-CG2		6, 2, 4, 0	
R2-BG2-CG2	2 reflector/ 5 fuel blocks 	2 (uniform)	2 (uniform)
R2-BG4-CG2		4 (uniform)	2 (uniform)
R2-BG4-CG1			1 (uniform)
R2-BG6-CG2		6 (uniform)	2 (uniform)
R2-BG6242-CG2		6, 2, 4, 2	
R2-BG6240-CG2		6, 2, 4, 0	

* F: fuel block, R: reflector block, BG: Bypass Gap, CG: cross-flow gap

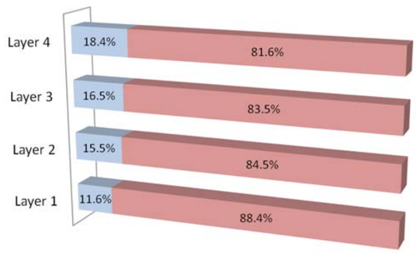
The isothermal flow is assumed at atmospheric temperature and pressure. Air density and viscosity are 1.185 kg/s and 1.831×10^{-5} kg/m-s, respectively. Mass flow rate is fixed as 0.8 kg/s at the inlet. The static pressure is applied for both the bypass and channel outlets. Other boundaries are set as solid walls. The standard k-ε model is used with the wall function for the turbulent flow simulation.

The computational grids are composed of hexagonal meshes for the bypass gap, hexagonal and prism meshes for the channels and the inlet, and the tetrahedral and prism meshes for the transition layer. The GGI treatment[3] is used for the interface of non-matching grid between the block channels, the transition layer, and the outlet pipes. The total number of nodes in maximum is about 10 million for the uniform bypass gap and 20 million for the non-uniform bypass gap.

3. Results

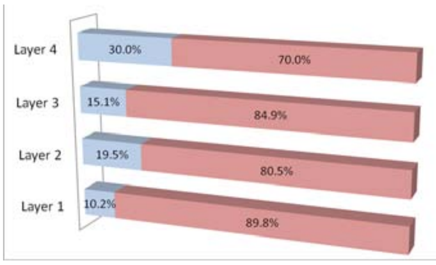


(a) F7-BG2-CG2

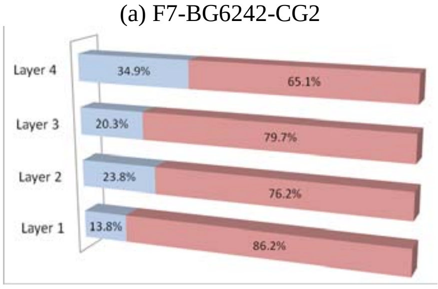


(b) R2-BG2-CG2

Fig. 2 Flow distribution for the uniform gap cases



(a) F7-BG6242-CG2



(a) R2-BG6242-CG2

Fig. 3 Flow distribution for the non-uniform gap cases

Figure 2 shows flow distributions for F7 and R2 cases with uniform gap size of 2mm both for the bypass and cross flow. The existence of reflector blocks increases the bypass flow. Bypass flow decreases as it approaches to the outlet. The largest crossflow occurs between Layer 1 and 2.

Figure 3 shows the results for the non-uniform gaps, which simulate the core at the end of cycle. It is clearly seen that the fraction of bypass flow is proportional to the local size of bypass gap. The R2 case reveals higher bypass flow than the F7 case, similar to the constant bypass gap case. Smaller gaps in Layer 1 and 3 reduce the bypass flow which should be large if the gap is uniform.

Table 2 summarizes bypass flow fractions at the inlet and outlet. The bypass flow increases as the gap size increases. The largest bypass flow at the outlet is 44.5% whereas the smallest bypass flow is 8.5%. The influence of cross gap size is small when comparing CG1 and CG2. The marked reduction of bypass flow is observed in the non-uniform gap case. Blocking the bypass gap at the bottom does not take effect on reducing the bypass flow at the inlet.

Table 2. Bypass flow fractions at the inlet and outlet

Cases	Inlet (%)	Outlet (%)
F7-BG2-CG2	14.0	8.5
F7-BG4-CG2	29.9	22.8
F7-BG4-CG1	29.7	23.4
F7-BG6-CG2	42.3	36.2
R2-BG2-CG2	18.4	11.6
R2-BG4-CG2	37.3	29.5
R2-BG4-CG1	36.9	30.3
R2-BG6-CG2	50.5	44.5
F7-BG6242-CG2	30.0	10.2
R2-BG6242-CG2	34.9	13.8
F7-BG6240-CG2	29.9	0.0
R2-BG6240-CG2	34.5	0.0

4. Conclusions

Preliminary CFD analyses were performed to investigate the flow distribution in the test section of the SNU multi-block air test facility. The results showed that

- The bypass flow highly depends on the bypass gap size and decreases at the outlet.
- The presence of reflector region results in an increase of bypass flow.
- The change of cross gap size has little effect on the bypass flow distribution.
- The non-uniform gap distributions give rise to locally varying bypass flow distribution.
- The effect of blocking the bypass gap is localized in the bottom region

Acknowledgements

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REFERENCES

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[3] ANSYS Inc, *ANSYS CFX Introduction*, Release 12.0, 2009.