Computational Assessment of Bypass Flow in a Multi-Block Air Test

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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. [1] The complexity of gap distributions in the core makes a system code selected as a major tool for the analysis, the models and correlations of which should be validated before applying to the analysis of the NHDD [2] core. An experimental facility is being constructed at Seoul National University for the generation of data for the validation.

In this paper, a preliminary analysis of bypass flow is performed to investigate the performance of a system code, GAMMA+[3], for a multi-block experiment conducted by SNU[4]. CFD analyses were carried out to compensate for the lack of data for the comparison in the multi-block experiment. A detailed comparison is made between CFD and GAMMA+ results.

2. Methods

2.1 CFD model

A schematic diagram of the SNU is illustrated in the CFD model layout of Fig. 1. The test section of the experiment consists of three layers and 11 columns of acryl blocks. Each layer includes three hexagonal blocks in the middle row, on each side of which there are two pentagonal and rectangular blocks. Most of the air flow coming from the inlet supplies into the channels which is provided in the block to mimic the coolant channels in the VHTR core block, and discharges at the channel outlet through mixing chambers. The other flow enters into uniform bypass gaps of 2mm between the blocks and discharges at the bypass outlet. A cross gap of 2mm (δ_c) is introduced in the main flow direction to examine the cross flow effect.

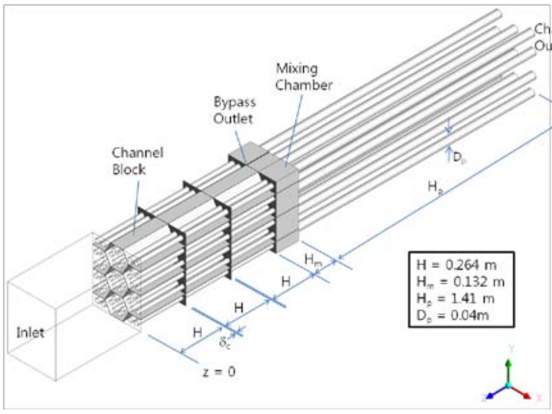


Fig. 1 CFD model layout

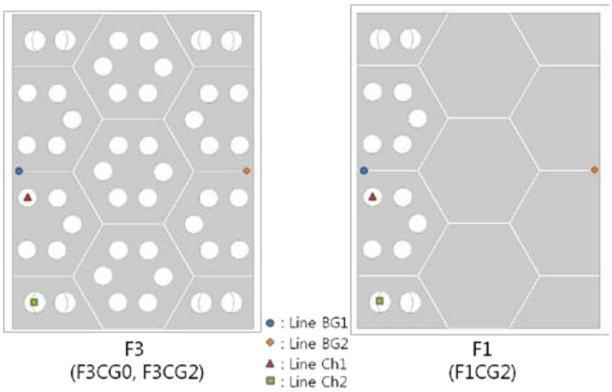


Fig. 2 Selected block arrangements

Two different block arrangements are selected, as shown in Fig. 2. One is three rows of channel blocks designated by F3 whereas the other is one row of channel blocks and two rows of not-channel blocks by F1.The pressure data in the experiment only exists along the line BG1 and BG2.

The isothermal flow is assumed at atmospheric temperature and pressure. For the boundary conditions, a mass flow rate is fixed at the inlet. The same 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 mixing chamber. The GGI treatment is used for the interface between the block channels, mixing chamber, and the outlet channels. The total number of nodes in maximum is about 2.7 million.

2.2 GAMMA+ model

GAMMA+ is a system thermo-fluid and safety analysis code developed at KAERI. Fig. 3 shows the GAMMA+ analysis model. To model all flow paths in the experiment, some modification was made. Flow channels in the blocks are rotated to be connected to the corresponding gap channels. The blocks having five channels are approximately treated as having four channels to match the number of side gap channels.

Pressure drop along the block and gap channel is modeled by the Haaland or Madams formula with the Reynolds number based on hydraulic diameter. The effect of the cross flow loss factor is considered by Kaburaki's correlation.[5]

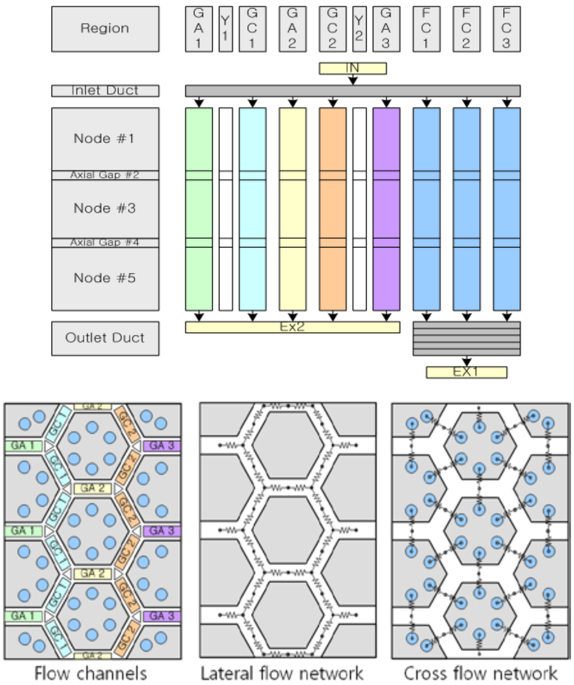


Fig. 3. GAMMA+ Analysis Model

3. Results

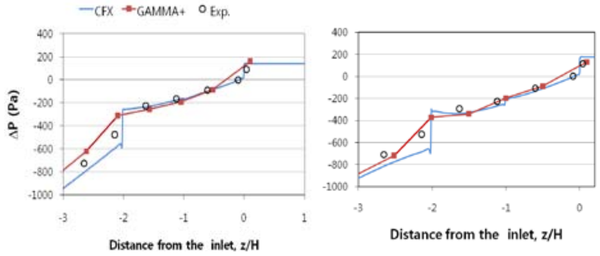
Pressure drops along the BG1 line in Fig. 2 are compared with the experimental data in Fig. 4. The distance from the inlet is normalized by the block height, H. The CFX and GAMMA+ results show a good agreement with the experiment, except for the region after the abrupt pressure drop across the cross gap between the second and third blocks. The CFX results over-predict the pressure drop across the second cross gap while the GAMMA+ results reveal less pressure drop.

Fig. 5 shows velocity vectors on the plane of the second cross gap. The cross flow from the block channels merges into the bypass flow at the BG1 line, which makes the steep pressure drop due to the flow blockage effect at the merging location as shown in Fig. 5. Some cross flow goes into the block of two flow channels at the corner.

The bypass flow fractions are summarized in Table 1. The analysis result for F3CG2 and F1CG2 cases shows a relatively high fraction of bypass flow, conservative in view of the effective cooling flow of the VHTR core. However, the F3CG0 case shows a higher value in the experiments. When considering that the trend of the two analysis results is similar, a careful consideration is needed for the F3CG0 case not only in the analysis but also in the experiment.

4. Conclusions

A preliminary study of bypass flow prediction was carried out by using a commercial CFD code (CFX) and the GAMMA+ code. The results show that the analysis can predicts the bypass flow with an adequate engineering margin. The CFD results can provide a supplementary explanation for the flow characteristic observed in the experiment in conjunction with the GAMMA+ results. The different bypass flow fraction observed in the F3CG0 case requires a further study and an experiment with more detailed data.



(a) F3CG2 (b) F1CG2

Fig. 4. Comparison of pressure drops along the line BG1for the F3CG2 case

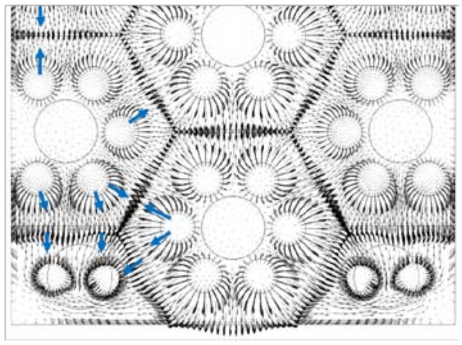


Fig. 5. Velocity vectors on the plane of the second cross gap

Table 1. Comparison of bypass flow fraction

Case	Inlet Flow Rate (kg/s)	Bypass Flow(%)		
		Exp.	CFX	GAMMA+
F3CG0	0.4226	13.39	12.01	12.42
F3CG2	0.4179	13.35	14.19	14.12
F1CG2	0.1775	29.69	30.02	29.99

Acknowledgements

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