Numerical Analysis of the Bypass Flow and the Flow Distribution Characteristics in the VHTR Core with Unstructured Non-conformal Mesh

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1. Introduction

VHTR(Very High Temperature Reactor) which aims at producing mass hydrogen is classified into PBR (Pebble Bed Reactor) type and PMR(Prismatic Modular Reactor) type. Between them, PMR type reactor is composed of the fuel blocks and reflector blocks stacked in a row. Due to this structural feature, lateral flow between the upper and lower blocks which is called cross-flow and interstitial flow between the blocks aside can be generated. These phenomena in all are called the bypass flow [1]. It makes the temperature of core outlet fall, so the temperature cannot reach the temperature which can produce hydrogen, that is over 900℃. In addition, by making the local temperature of fuel rise, a bad effect on the thermal efficiency and safety is exerted.

As the researches on the bypass flow have been insufficient so far, it is necessary to evaluate the bypass flow quantitatively and analyze the flow distribution in the core. The experimental methodology in analyzing the flow distribution and bypass flow in the whole core is so difficult to perform that it is useful to access by CFD(Computational Fluid Dynamics) analysis. In this study, the evaluation of the bypass flow and the flow distribution characteristics in the core is suggested by CFD analysis.

2. Core Structure and Scope of Analysis

GT-MHR(Gas Turbine-Modular Helium Reactor) developed by GA(General Atomics) in USA as a kind of PMR type reactor was selected as a model for this research [2]. Figure 1 presents upper part of reactor core of GT-MHR.

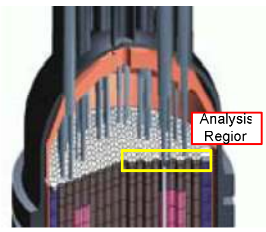

Fig. 1. Schematic of reactor core

In reactor core, coolant flows upward through the risers and comes down through the space of upper plenum. Then it flows in the coolant channels and interstitial gaps between the blocks. In this research, such flow distribution characteristics and bypass flow were investigated. As the annular shape of reactor core is symmetrical around azimuthal direction, the analysis was performed on 1/4 size of reactor core in order to reduce the computing time reasonably.

3. Numerical Analysis

In this section some of the analysis techniques are described. This statement includes analysis condition and the principle of mesh generation.

3.1 Analysis Condition

In this research, the meshes were generated using GAMBIT 2.2, and the numerical analysis was performed by FLUENT 6.2.16 code [3, 4]. Shear Stress Transport (SST) k-ω model was selected as the turbulence model. The coolant inlet condition is shown in Table I. The operating fluid in CFD analysis is helium gas same as that of actual reactor, GT-MHR. The mass flow rate, 80kg/s is same amount of 1/4 mass flow rate of the whole core.

Table I: Coolant Inlet Condition

Operating fluid	Helium
Fluid density [kg/m^3]	3.868
Mass flow rate [kg/s]	80
Operating pressure [bar]	70

3.2 Mesh Generation and Statistics

Due to the difference between dimensions of upper plenum and those of coolant hole and gap in core, their mesh scales are different from each other. If much smaller mesh scale of coolant channels and gaps is applied to that of upper plenum, so excessive computing capability is demanded that it is difficult to analyze with current computing power. So as to apply such dissimilar scales of these two parts together, the unstructured non-conformal mesh was introduced.

Compared to the structured mesh the unstructured mesh satisfies reasonable node distribution and element sizing creation. In addition, the capability of local mesh modification is also easily accessible [5]. At the interface between the unstructured meshes of upper plenum and core blocks in different mesh scales, the information of the prior volume cells is delivered to the next volumes with non-conformal methods. With this non-conformal unstructured mesh, the efficiency of power and time of computing gets enhanced remarkably.

Figure 2 and 3 show the meshes of core blocks and that of upper plenum respectively. The mesh statistics is summarized in Table Ⅱ.

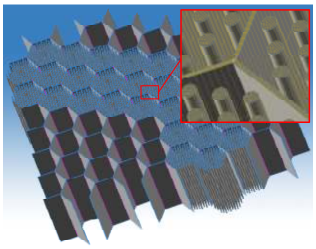

Fig. 1. Core block mesh generation

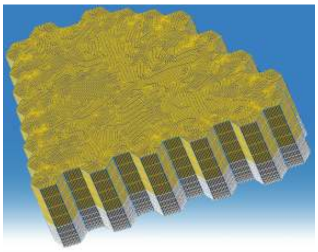

Fig. 2. Upper plenum meshes

Table Ⅱ: Mesh Statistics

	Number of nodes	Number of elements
Upper plenum region	246532	223368
Core region	1884542	1397830

4. CFD calculation Results

The velocity magnitude distribution in the vicinity upper plenum and core region is presented in Fig. 4.

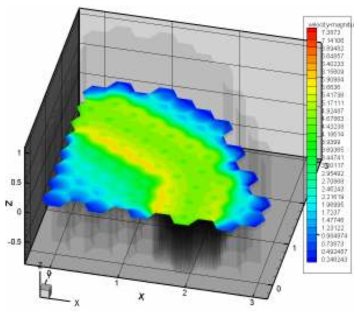

Fig. 3. Flow velocity distribution in 1/4 core

The velocity of fuel region is higher than that of inner or outer (side) reflector. The average velocity in this fuel region is approximately 5.0 ~ 5.5 m/s, and the maximum velocity reaches to 6.0 m/s. The maximum value in core region is about 29.5 m/s on the other hand. The coolant flow from inner reflectors to central fuel blocks is larger than that from side reflectors to central blocks. Therefore the velocity at the interface between inner reflector and fuel region is larger than that of other parts.

Figure 5 illustrates the ratios of each coolant hole flow to the whole inlet coolant flow. By little difference, the mass flow rate of central fuel blocks is the greater, and that of outer part is the next. As the radial component is dominant in the velocity of inner or side reflector, the axial velocity of the central part of the fuel region is higher in Fig. 4, actually. In the whole, the mass flow rate is uniform in the fuel region. And the total mass flow rate through the coolant channels in fuel blocks is 79.4%, in other words the bypass flow rate is 20.6%.

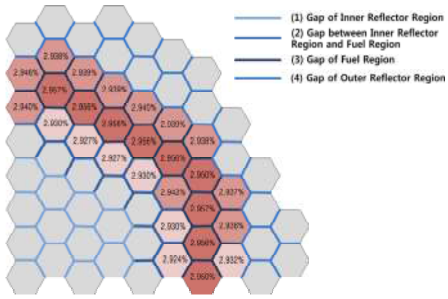

Fig. 5. Flow distribution of each fuel block

5. Conclusions

Unstructured non-conformal mesh made reasonable combination of sparse meshes of upper plenum and dense meshes of coolant holes and gaps. With this method, a large scale calculation of the 1/4 core was performed effectively. Consequently, the evaluation of the bypass flow and the flow distribution characteristics was accomplished. Furthermore, this mesh generation method can be applied to the analysis of the whole multi-layer core after this research.

ACKNOWLEDGMENTS

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