Effect of Permanent Side Reflector on the Temperature Variation in the VHTR Core

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1. Introduction

A Very High Temperature Reactor (VHTR) has been selected as one of the Gen-4 reactors in Korea. The high coolant temperature of the VHTR has enabled Nuclear Power Plants (NPPS) to be applied for both electrical and non-electrical applications. A gas turbine, which has a high efficiency, may be connected to the VHTR. The large heat capacity of the coolants might provide process heat and generate hydrogen. However, the high operation temperature of the VHTR needs careful studies to use safely and efficiently. The temperature and pressure conditions range from 490°C to 950°C, 7MPa. GAMMA+ was developed to predict the overall phenomena of the VHTR system. The GAMMA+ algorithms focused on the transient condition for the systems. Therefore, the computational control volumes are coarse for reducing the computational time. However, there are difficulties calculating the temperature gradient in the fuel blocks in detail. There is a demand to predict a hot spot and temperature distribution in the reactor core to apply a thermal stress and find the fuel temperature margin. Computational Fluid Dynamic (CFD) tools can be an option to model the VHTR. However, the fluid has to be solved in three dimensions. The long computational time and heavy burden of the memory size have called for an alternative option. Therefore, steady-state thermal-fluid analysis code, Core Reliable Optimization & thermo-fluid Network Analysis (CORONA)[1][2], has been developed at Korea Atomic Energy Research Institute (KAERI). The CORONA is a specialized code to solve the prismatic gas cooled reactor.

CORONA analyzed the solid area using a pre-generated mesh in previous studies [3][4]. However, the generated meshes had only a hexagonal structure form for the prismatic VHTR. It was difficult to model the permanent side reflector (PSR) with the original shape. In the present studies, the effect of the boundary condition of the PSR was analyzed using new mesh types.

2. Methods and Results

2.1 Methods

The fluid region is solved using the one-dimensional governing equations below [3][4]:

$$\frac{\partial \rho_f}{\partial t}+\frac{\partial(\rho_f wA)}{A\partial z}=0 \quad (1)$$

$$\frac{\partial(\rho_f w)}{\partial t}+\frac{\partial(\rho_f w^2 A)}{A\partial z}+\frac{\partial p}{\partial z}+\rho_f g\cos\theta+f\frac{\rho_f w|w|}{2D_h}=0 \quad (2)$$

$$\frac{\partial(\rho_f C_f T_f-P)}{\partial t}+\frac{\partial(\rho_f wAC_f T_f)}{A\partial z}-q'''_{conv}=0 \quad (3)$$

The temperature at the each node was calculated using the energy balance equation below along the axial direction in the previous model under steady-state conditions.

$$\rho_f wC_f T_{f_I}=\rho_f wC_f T_{f_{I-1}}+q'''_{conv,I}\delta z \quad (4)$$

Fig. 1 shows the CORONA computational cells with and without a PSR. Without a PSR, it is a little difficult to give the exact outer boundary conditions.

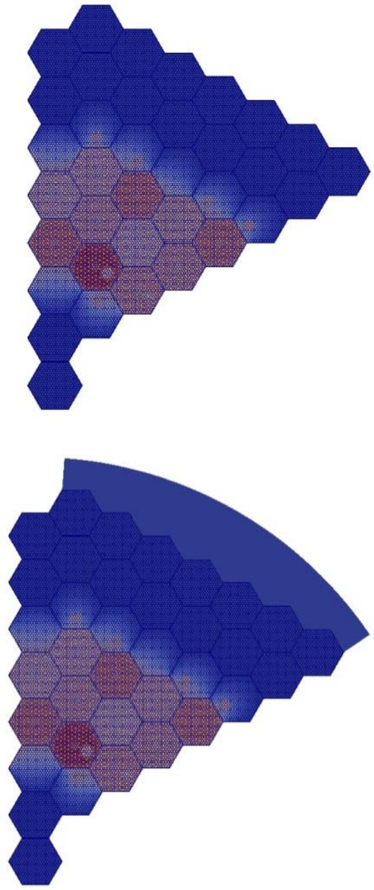

Fig. 1. CORONA mesh for one sixth core with/without PSR

2.2 Verification

A new algorithm is inserted into the CORONA code with a structured mesh to predict the PSR. To guarantee the modified code, a single assembly with an arc shaped reflector, shown in Fig. 2, was calculated and compared with the CFX results. The CFX, Ver. 15[5], with the k-ε turbulence model was applied in the present study.

The total computational nodes were 46,755,990 and the fluid nodes were 16,919,388.

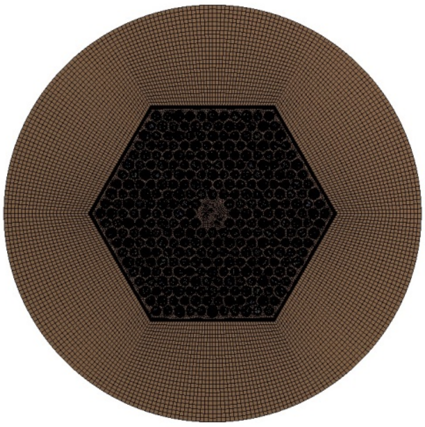

Fig. 2. CFX meshes for single fuel assembly with PSR

The core power was set to 3.422 MW. The inlet temperature and flow rate were 490°C and 1.2072 kg/s, respectively. The two outer boundary conditions, adiabatic and fixed temperatures of 300°C, were compared.

Figs. 3 and 4 show a comparison of the temperature distribution for the fixed temperature boundary condition and adiabatic boundary condition. The results of CORONA (bottom of each Fig.) match well with the data by the CFX calculations (top of each Fig.).

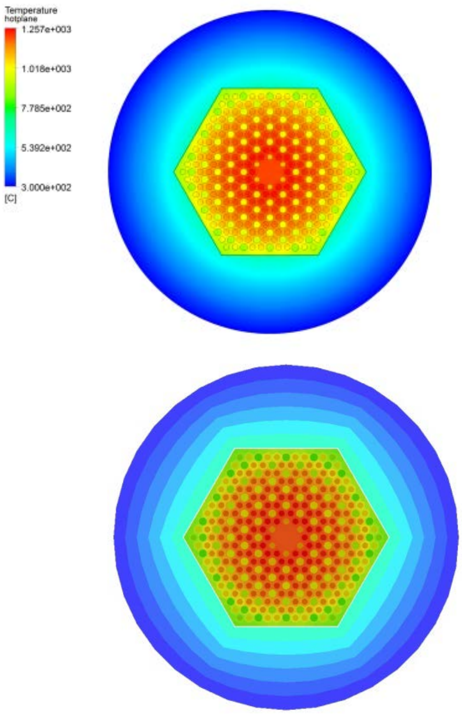

Fig. 3. Temperature distribution comparison for single assembly with fixed boundary temperature condition (Top: CFX, Bottom: CORONA)

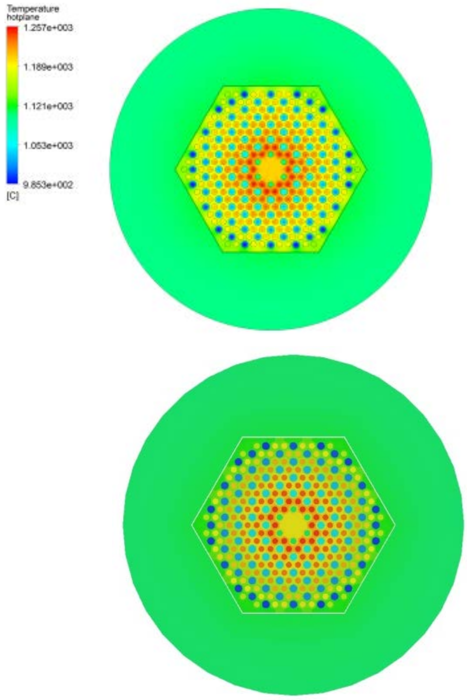

Fig. 4. Temperature distribution comparison for single assembly with adiabatic boundary condition (Top: CFX, Bottom: CORONA)

Figs. 5 and 6 show the temperature distribution for the one-sixth core of MHTGR350 with the CORONA code. The inlet temperature of the coolant is 259°C and the power is 58.33MW. The fixed temperature boundary condition (coolant inlet temperature) at the outside of the PSR is imposed in Fig. 5. Fig. 6 shows the results of the calculation with the additional bypass flow outside the PSR. Because of the additional bypass flow passage, which resulted in reducing the coolant flow rate into the coolant channels, the temperature of reactor core increased in Fig. 6. However, the temperatures of the PSR did not show large differences compared to the fixed temperature condition.

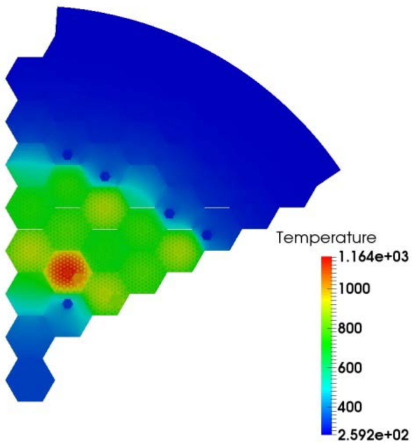

Fig. 5. MHTGR350 temperature distribution with fixed inlet temperature boundary condition

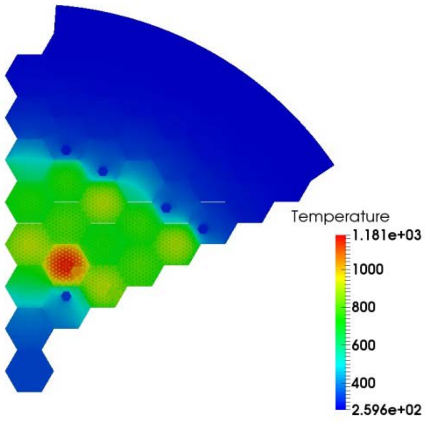

Fig. 6. MHTGR350 temperature distribution with bypass flow boundary condition

3. Conclusions

The PSR blocks are considered in the prismatic VHTR calculation with the CORONA code. The temperatures of a single assembly with an arc shape reflector by the CORONA code were verified with the results by the CFX calculation. The temperature distributions of the PSR regions did not show significant differences depending on the fixed inlet temperature boundary condition and bypass flow condition. However, if there is a bypass flow outside of the PSR, the hot spot temperature changes by the mass flow rate change. More boundary conditions will be applied to simulate the various operating conditions in the further studies.

Acknowledgements

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