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CORONA Code Verification on One-sixth Core of VHTR

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1. Introduction

Very High Temperature Reactor (VHTR) is chosen as one of the Gen-4 reactors in Korea. The VHTR uses a helium gas as a coolant to operate in high temperature condition. The high operating temperature of the VHTR has extended the applications of the Nuclear Power Plants (NPPS). The gas-turbine that uses Rankine-cycle may connect to the VHTR. The high temperature coolant could provide process heat and make hydrogen. However, the high temperature condition of 490°C to 950°C in the reactor core demands various researches to use VHTR safely and efficiently. Korea Atomic Energy Research Institute (KAERI) has been developing GAMMA+ code to simulate the transient phenomena in the VHTR system. But, it has difficulties to find local temperature distributions precisely in the fuel blocks due to coarse grids. It is necessary to calculate the hot spot and temperature distribution in the reactor core to apply thermal stress and find the fuel temperature margin during a normal operation. KAERI is developing steady-state thermal-fluid analysis code, Core Reliable Optimization & thermo-fluid Network Analysis (CORONA)[1][2] to investigate the local temperature distribution in the prismatic VHTR. Various studies has been conducted to verify the CORONA code up to now. However, the full core of VHTR was difficult to compare with commercial Computational Fluid Dynamic (CFD) tool due to insufficient computer hardware performances. On the present study, one-sixth core of VHTR was selected to compare the calculated data by commercial Computational Fluid Dynamic (CFD) tool with advanced CPUs and RAM memories.

2. Numerical Modeling

The CORONA code adopted a network model to predict various coolant channels in the solid core. The code has developed to get the local thermo-fluid information accurately and fast. The code solves a fluid as one-dimension and solves a solid as three-dimension like CFD tools. The computational grids of the solid area can be generated easily with a unit-cell concept[3][4].

2.1 Governing Equations

A fluid region is solved by the below one-dimensional steady-state governing equations[3][4].

$$\frac{\partial(\rho_f wA)}{A\partial z}=0 \tag{1}$$

$$\frac{\partial p}{\partial z}+f\frac{\rho_f w|w|}{2D_h}=0 \tag{2}$$

$$\frac{\partial(\rho_f wAC_f T_f)}{A\partial z}-\frac{1}{A}\frac{q_f^{conv}}{\partial z}=0 \tag{3}$$

The temperature on the each node was calculated below energy balance equation along the axial direction on the previous model under steady-state condition.

$$\rho_f wC_f T_{f\,I}=\rho_f wC_f T_{f\,I-1}+q'''_{conv,I}\delta z \tag{4}$$

2.2 Models and Correlations

The turbulent heat transfer coefficient was calculated by the following correlations[5].

Modified Dittus-Boelter

$$Nu_{tur}=0.021\times Re^{0.8}\times Pr^{0.4} \tag{5}$$

McEligot

$$Nu_{tur}=0.021Re^{0.8}\,Pr^{0.4}\left(\frac{T_s}{T_f}\right)^{-0.5}\left(1+\frac{x}{D}\right)^{-0.7} \tag{6}$$

Gnielinski

$$Nu_{tur}=\frac{(f/8)\times(Re-1000)\times Pr}{(1+12.7\times\sqrt{(f/8)}\times(Pr^{2/3}-1)}\left(\frac{T_w}{T_b}\right)^{-0.45}\left(1+\left(\frac{x}{D}\right)^{-2/3}\right) \tag{7}$$

2.3 CFD model

ANSYS CFX, Ver. 17.2[6] is applied to solve one-sixth core of VHTR. The RNG $\kappa-\varepsilon$ turbulence model is selected on the present calculation.

2.4 Modeling

Fig. 1 represents one-sixth core of VHTR. It consists of upper plenum, top reflector, 6 fuel blocks and bottom reflector. The coolant mass flow is 26.24549kg/s. The inlet temperature and pressure are set to 259°C / 7MPa. The average power density is 25.67kW/m^3. The side plane is treated as a wall to compare the results easily.

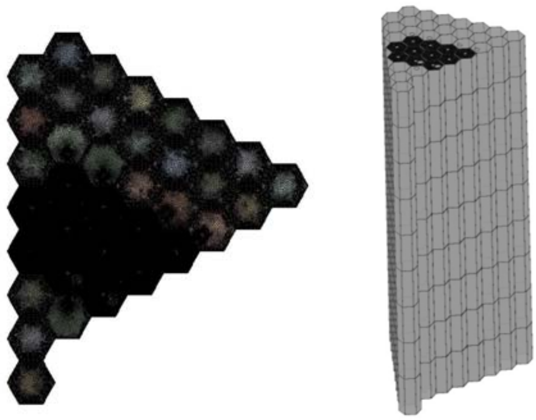

Fig. 1. One-sixth core model of VHTR

Fig. 2 shows column numbers in the one-sixth core and the power peaking factors in the fuel columns. The axial power is assumed as uniform.

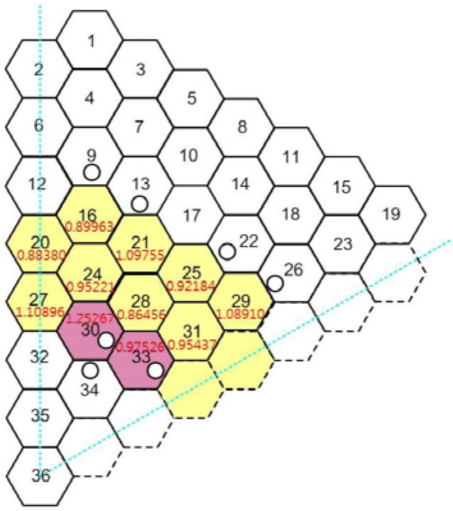

Fig. 2. Column numbers and power peaking factor

3. Numerical Calculation

The numbers of computational nodes used in the CFX are 70,425,872 in the fluid region and 77,670,155 in the solid region. The computational time consumed 9 days 7 hours with 8 CPUs. The RAM memory used on the present calculation was 296GB. The number of computational nodes used in the CORONA are 72,912 in the fluid region and 15,190,224 in the solid region. The computational time was 33 minutes with 12 CPUs and 118GB of RAM.

Table I shows the mass flow distributions at the outlet with 2mm bypass gap. The maximum difference was 2.78% in the control hole channel.

Table I: Mass Flow Distribution

Channel	Coolant	Bypass	Control Hole
	kg/s	kg/s	kg/s
CFX	15.9	1.468	8.88
CORONA	15.673	1.441	9.134

The maximum temperatures of the fuel columns are written in Table II.

Table II: Maximum Temperature in the Fuel Columns [ºC]

Column	CFX	CORONA	Column	CFX	CORONA
16	779	763	28	756	779
20	769	741	29	905	935
21	912	960	30	992	981
24	813	815	31	815	819
25	794	753	33	809	776
27	916	961			

Fig. 3 and Fig. 4 show the temperature distribution at the hot spot plane and the axial temperature profiles where the radial peaking factor of the fuel column is larger than 1.0. The maximum temperature difference was 5% in the column 21.

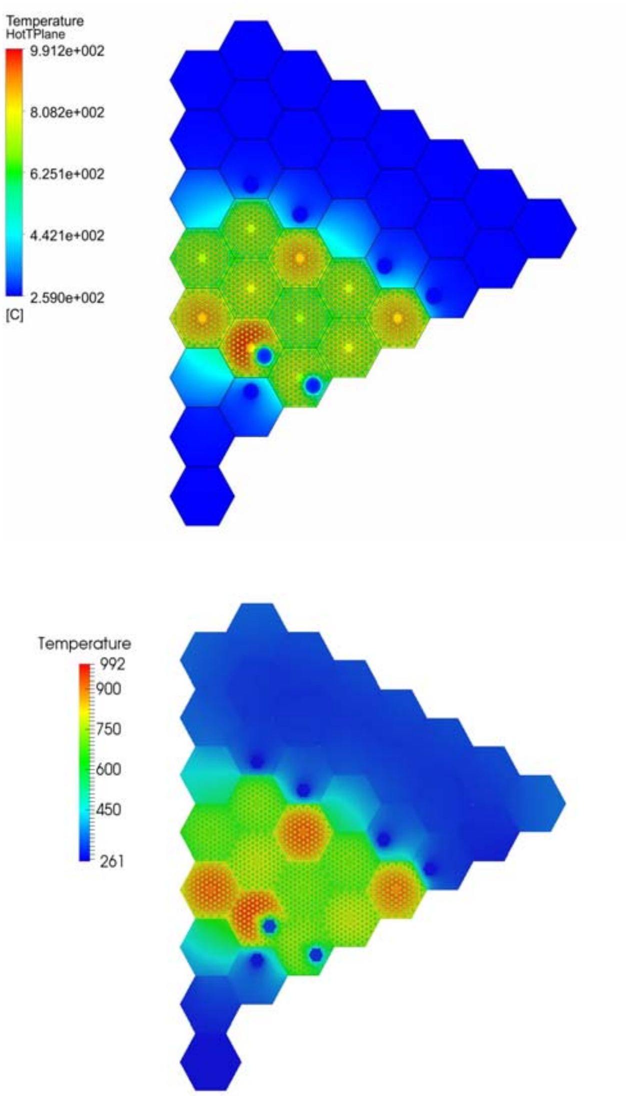

Fig. 3. Temperature distributions at the hot spot plane(Top : CFX, bottom : CORONA)

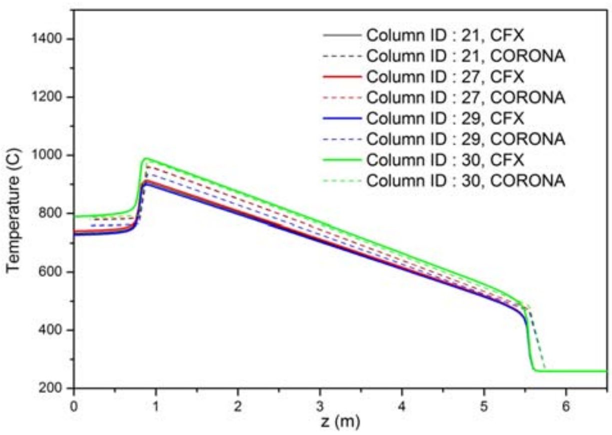

Fig. 4. Axial temperature profiles at fuel columns

5. Conclusions

In this work, one-sixth core of VHTR was investigated to compare the thermo-fluid data by the CORONA and CFX calculations. With the advanced CPUs and extended RAM memories, the one-sixth core of VHTR could be calculated with CFD S/W. The calculated data by the CORONA code well agree with the calculated data by the CFX. But ~400 times longer the computing time was spent for the CFX calculation. The 10 fuel block layers with symmetric condition will be studied in the further research.

Acknowledgements

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