CORONA Verification on the Pin-By-Pin Power Distribution of the VHTR Core

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1. Introduction

Core Reliable Optimization & Network thermo-fluid Analysis (CORONA)[1][2][3] is the thermal-hydraulic code to simulate prismatic gas cooled reactor. The CORONA has been developing and verifying to design Very High Temperature Reactor (VHTR) after Korea Atomic Energy Research Institute (KAERI) has chosen the VHTR as one of Gen-4 reactors in Korea. The selected VHTR is graphite moderated and helium cooled prismatic reactor. The helium coolant is heated up without phase change. Therefore, the VHTR may use the Brayton cycle which is more efficient than the Rankine cycle. Moreover, the VHTR can also provide process heat due to high temperature coolant. The other benefit is passive safety. The residual heat of the VHTR might be removed by the natural convection and radiation even in the accident case. However, the careful research is necessary to design and operate the VHTR efficiently and safely. Because the VHTR operates under the high temperature and pressure condition range of 490°C to 950°C, 7MPa for long time, the thermal stress and creep problem should be resolved. To get an accurate temperature distribution in the reactor core, the detailed study is in demand in the solid structure. Originally, GAMMA+ code has developed to simulate the behavior of the coolant and fuel block. However, it is focused on the transient system. The solid structures are simplified to enhance the computational speed. GAMMA+ might give average fuel temperature or maximum temperature at the each structure. However, it is difficult to provide accurate temperature gradient in the reactor core. Computational Fluid Dynamic (CFD) tool may provide most accurate results, but still the burden of the computational time and the complex of mesh generation remain. The CORONA solves fluid as one dimension and solid as three dimensions like CFD. Thus, CORONA might reasonable temperature distribution with fast calculation time. On the present study, the temperature by the different power level in the each fuel compact has been compared with CFX, CFD tool.

2. Methods and Results

2.1 Pin power distribution

The fuel assemblies in the VHTR core are about 66~102 depending on the power. Each assembly has different power level to get uniform temperature profile during the normal operation. The power peaking varies by the position, type of the fuel assembly and so on. The previous study focused on the average power to the each fuel assembly. It was assumed that the power peaking might differ for the each fuel assembly, but the power of fuel compact in the same fuel assembly assumed as same. This approach could under-estimate the hot spot temperature of the fuel assembly since the approach could not reflect the geometry effect between coolant channels and fuel compact array. If each fuel compact has different power level, the hot spot temperature might vary although the average assembly power is same. The simple pin-power distributions are selected to verify the CORONA code and the detailed power distribution in the single fuel assembly is applied to predict maximum fuel temperature on the present study.

Fig. 1 shows the schematic of the standard fuel assembly. It has 210 fuel compact holes and 108 coolant channel. The maximum fuel temperature would change by changing the each fuel compact power level. On the present study, The CORONA code was verified with CFX using three types of power level, i.e., uniform, line-by-line, top and bottom. Line-by-line power level is that the fuel compacts in the same horizontal line in the Fig. 1. has the same power level. Top and bottom power level is that top and bottom half of assembly has different power level. Fig. 2 shows mesh generation of standard fuel assembly using ANSYS design modeller.

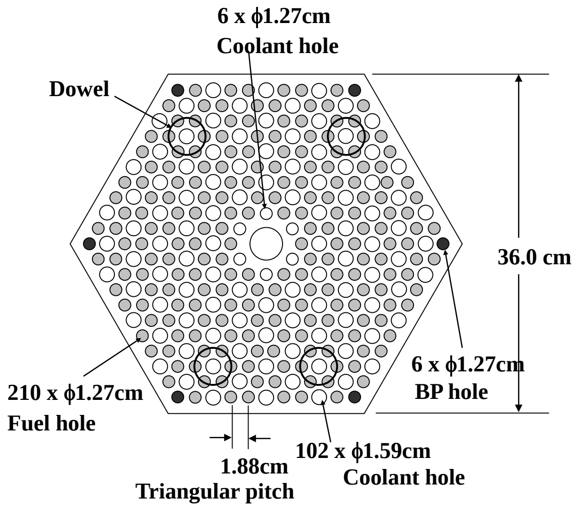


Fig. 1. Schematic of standard fuel assembly

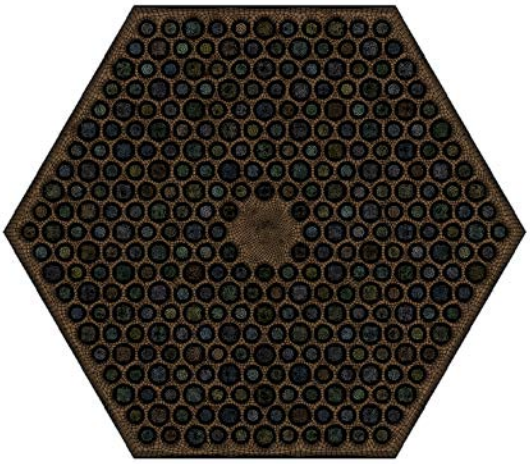


Fig. 2. Mesh generation of standard fuel assembly

The power level at the each fuel compact line is shown in Fig. 3. The average power density of fuel compact is 2.84E+7W/m^3. The power peaking values of the fuel compacts in the fuel assembly are set along the vertical-wise to calculate simply in Fig. 3.

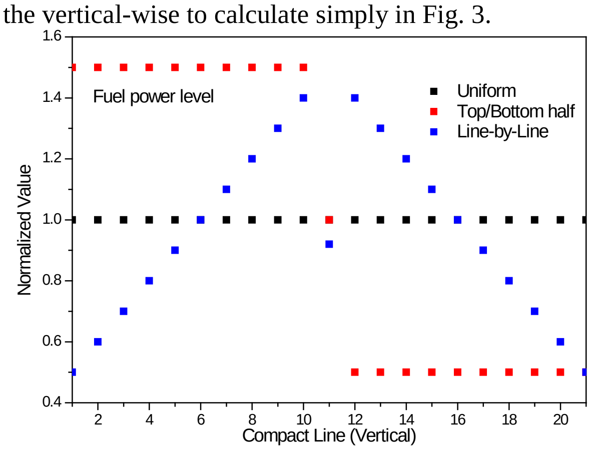


Fig. 3. Normalized power level of fuel compact

One dimensional fluid equation which is used in the CORONA code is written below.

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

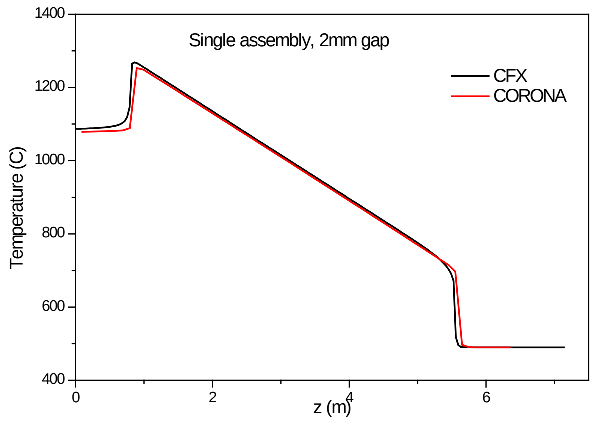
$$\frac{\partial(\rho_f w)}{\partial t} + \frac{\partial(\rho_f w^2 A)}{A\partial z} + \frac{\partial p}{\partial z} + \rho_f g\cos\theta + f\frac{\rho_f w|w|}{2D_h} = 0 \quad (2)$$

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

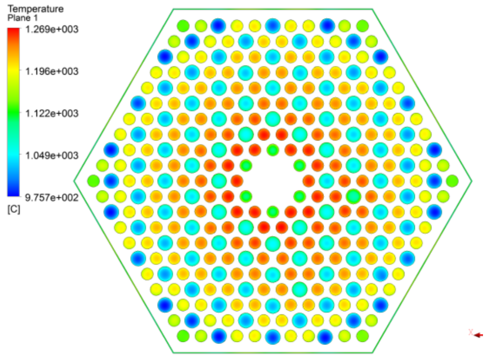
The RNG - κ-ε turbulence model was used in the CFX calculation.

2.2 Results

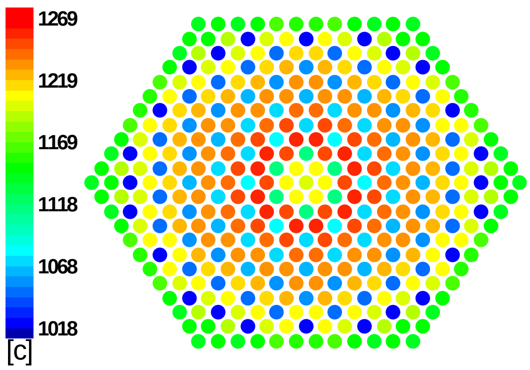
Fig. 4~6 show the axial temperature profile at the hot spot position and temperature distribution at the hot spot plane depending on the power peaking value. The results of CORNA well agree with the CFX data.



(a) Hot spot fuel temperature along the axial direction

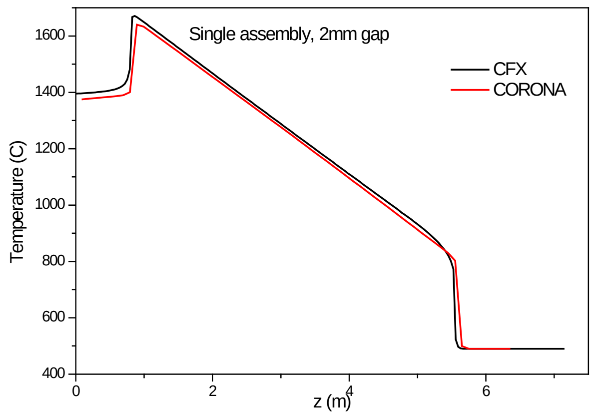


(b) Temperature distribution of CFX

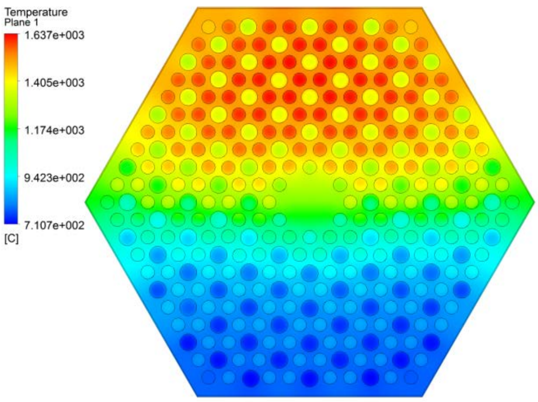


(c) Temperature distribution of CORONA

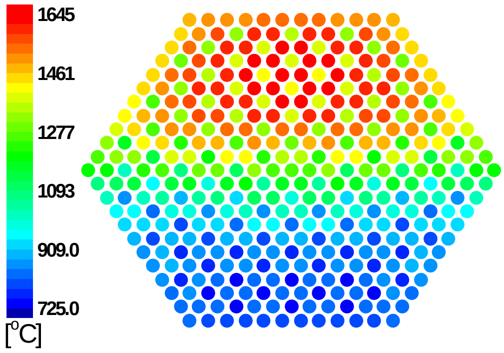
Fig. 4. Temperature comparison with the uniform power



(a) Hot spot fuel temperature along the axial direction

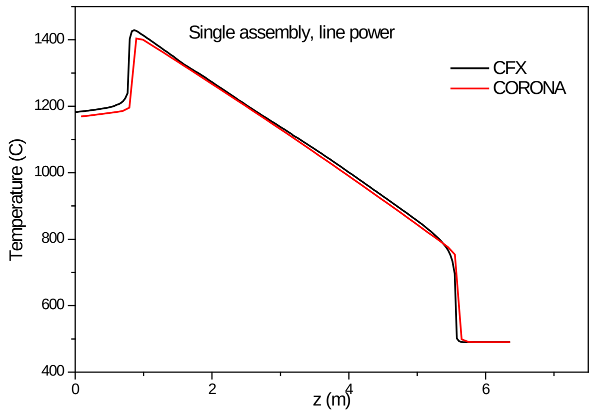


(b) Temperature distribution of CFX

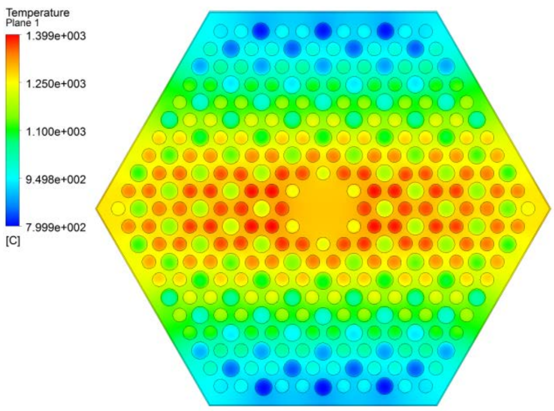


(c) Temperature distribution of CORONA

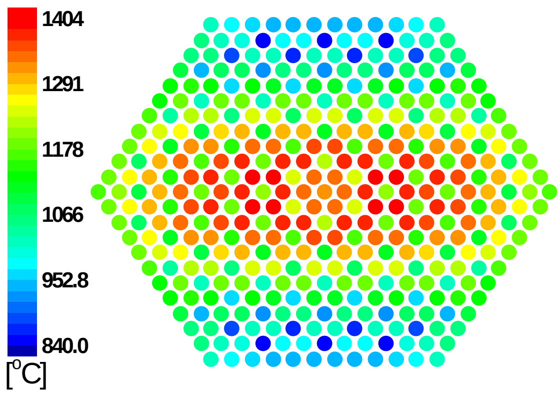
Fig. 5. Temperature comparison with the Top/Bottom half power



(a) Hot spot fuel temperature along the axial direction



(b) Temperature distribution of CFX



(c) Temperature distribution of CORONA

Fig. 6. Temperature comparison with the line-by-line power

3. Conclusions

The CORONA calculations with pin-by-pin power distributions are compared with the CFX results. The power value has been set uniformly at the each fuel assembly up to now. The different power at the each fuel compact might give different temperature distribution on the hot spot fuel temperature. The fuel temperature predicted by CORONA using the pin-by-pin power distribution was well matched with the CFD calculation. The more complex pin-power distribution will be studied to find flat and lower hot spot temperature in the further research.

Acknowledgements

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[2] N.I. Tak, S. N. Lee, M.H. Kim, and H.S. Lim, “One-dimensional Flow Network Model for Thermo-Fluid Analysis of Prismatic Gas-Cooled Reactor Core”, Transactions of the KNS Autumn Meeting, Gyeongju, Korea, October 24-25, 2013.

[3] S. N. Lee, N.I. Tak, M.H. Kim, and J.M. Noh, “Thermo-Fluid Verification of Fuel Column with Crossflow Gap”, Transactions of the KNS Autumn Meeting, Gyeongju, Korea, October 24-25, 2013.