Control Rod Heating Analysis of High Temperature Gas cooled Reactor

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1. Introduction

High Temperature Gas-cooled Reactor (HTGR) is designed to operate under the high temperature and pressure condition. Therefore, various thermal-fluid studies have been conducted to utilize the HTGR safely and efficiently. However, there is few studies on the thermal behavior on the control rod. The control rod is exposed to a high temperature coolant flow. Moreover, it is heated by the nuclear reaction with the neutron. The thermal-fluid analysis on the control rod is necessary to ensure that the control rod temperature does not exceed the limit of material. General Atomics (GA) studied the control rod thermal analysis on the FORT ST. VRAIN with simple fuel block modeling. Korea Atomic Energy Research Institute (KAERI) has developed the Core Reliable Optimization & thermo-fluid Network Analysis (CORONA)[1] code to predict the thermal-fluid phenomena in the reactor core of the HTGR. The CORONA code solved the fluid only in the control rod hole at the previous studies. In the present study, the solid region of control rod with heat generation is calculated with the CORONA and compared with the results of the CFX Ver. 19[2].

2. Methods and Results

The CORONA code solves the fluid as one dimension and the solid as three dimension. The solid region modelling of control rod is newly adopted in the present study. The control rod in the CORONA code was solved with cylindrical one dimensional equation. The governing equation is followed.

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda \frac{\partial T}{\partial r}\right) + q'''\delta(r) \quad (1)$$

The single control fuel elements is considered to be verified by comparing the results of the CORONA with the results of the CFX.

2.1 Control Rod Model

The control rod in the present study consists of outer cladding, outer gap, absorber material, inner gap, inner cladding and inner helium as shown in Fig. 1. The helium coolant in the region of R6~R7 in Fig. 1 comes from the small gap between the hole of the graphite block and the control rod. It was reported that there is also small fraction of coolant flow in the region of R1. However, the mechanism is complex and difficult to simulate with CFD tools. Therefore, R1 region in Fig. 1 is treated as adiabatic condition in the present study. This assumption results in more conservative temperature profile in the rod.

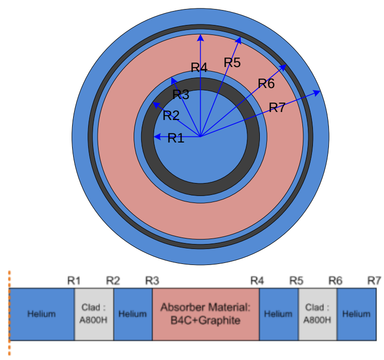


Fig. 1. Schematic of control rod

2.2 CFX Model

The control fuel element used in the CFX is shown in Fig. 2. It consists of plenum, top reflector, 6 fuel blocks and bottom reflector. The height of each block is 80cm.

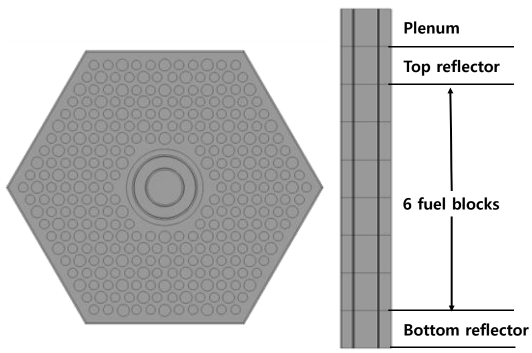


Fig. 2. Computational domain of control fuel element in the CFX

The boundary conditions in the simulation are summarized in the Table I.

Table I: Boundary conditions

	Value
Power density in fuel compact (MW/m^3)	25.67
Power density in control rod(MW/m^3)	2.567(10% of fuel power density)
Mass flow(kg/s)	1.43
Inlet Temp.(°C)	259

The RNG κ- ε model is applied. The total number of nodes in the coolant region are 6,333,432. The nodes in the solid region are 3,914,511. The cladding material was A800H and the absorber material was assumed as the combination of B_4C+graphite. The control rod was inserted until the bottom of the third fuel block from top position.

2.3 Results

Fig. 3 shows the temperature comparison of the CFX and the CORONA calculations in the control rod. The maximum temperature difference was 7°C. Fig. 4 shows the axial temperature distributions at the inner cladding surface. The calculated results by the CORONA well matched with the results of the CFX. It should be noted that one-dimensional approximation of CORONA gives sufficiently accurate results.

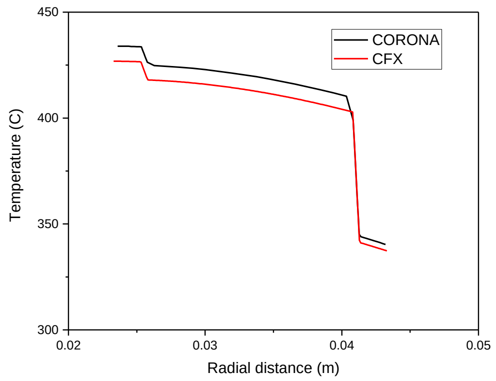


Fig. 3. Radial temperature distribution in the control rod

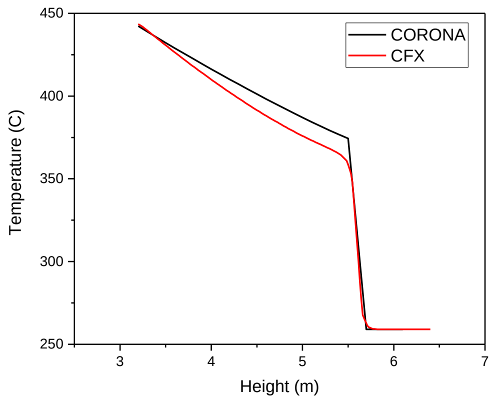
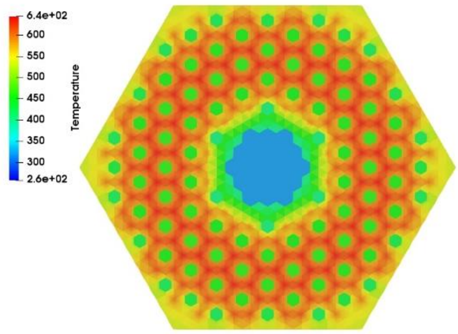
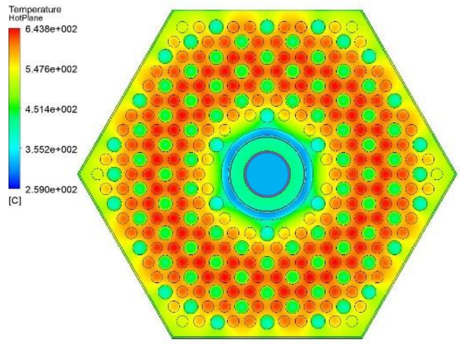


Fig. 4. Axial temperature distribution in the control rod

Fig. 5 shows the temperature distribution in the radial plane of the CORONA (top) and the CFX (bottom) at the bottom of the second fuel block from the top. The temperature distribution of the CORONA was drawn with the ParaView S/W[3]. The vtk file format in the CORONA does not model the control rod region in the present version. Therefore, it shows different temperature profile inside the solid control rod region. The fluid temperatures of the coolant hole and control hole well agree with those of the CFX as well as the solid temperatures in the fuel and graphite regions.



(a) CORONA



(b) CFX

Fig. 5. Radial temperature distribution in the fuel block

3. Conclusions

Assurance of the thermal integrity of the control rod during normal operation is important due to high coolant temperature. The temperature of the control rod in the control fuel element was calculated and compared between the CORONA and CFX. The cylindrical one dimensional equation adopted in the CORONA code well matched with the results of the CFX. The further studies with the MHTGR350 core will be conducted to ensure the limit of the control rod material temperature.

Acknowledgements

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[1] N. I. Tak, S. N. Lee, M. H. Kim, H. S. Lim, and J. M. Noh, "Development of a Core Thermo-Fluid Analysis Code for Prismatic Gas Cooled Reactors," *Nucl. Eng. Technol.*, vol. 46, no. 5, pp. 641-654, 2014.
[2] www.ansys.com
[3] www.paraview.org