Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Evaluation of the Radial Effective Conductivity for VHTR Standard Fuel Block

Bong Hyun Cho *, Jae Man Noh
Korea Atomic Energy Research Institute, DAEDEOK-DAERO 989-111, YUSEONG-GU, DAEJEON, KOREA
**Corresponding author: bhcho1@kaeri.re.kr*

1. Introduction

GAMMA+ code solves the temperature field of the solid part and fluid part independently, by modeling the reactor core as porous media. And then, it solves two temperature fields of solid parts which are divided as 1-D fueled zone and multi-D un-fueled zone, simultaneously. In this code, a radial effective conductivity is used for simplicity in calculating un-fueled zone, where this value is expressed as the sum of the conduction through the helium coolant and graphite moderator, and the cavity radiation heat transfer between coolant flow path and fuel block as shown in Fig. 1[1]. Actually, GAMMA+ uses the value of the radial effective conductivity which is obtained through the correlations generalized by the void fraction.

In order to obtain the most accurate value for radial effective conductivity, the full modeling of the actual fuel block would be needed. In this paper, CFD code, Fluent is applied to predict the accurate radial effective conductivity for a standard fuel block of VHTR reactor.

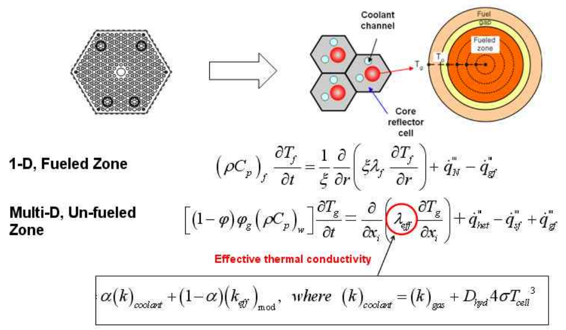


Fig. 1 Summary of GAMMA+ Scheme

2. Methods and Results

2.1 CFD Method

In order to simulate the radiation heat transfer through the cavity between the blocks, the calculation domain has been allocated one whole standard fuel block at the center and two half sized block on both sides of the central block.

To obtain overall heat transfer through the fuel block, a temperature gradient of 200K was given by assessing one hot side as a heat source and the other cold side as a heat sink. And the hot and cold side temperatures are arbitrary defined assuming that the mean temperature ranged from 800K to 1,700K.

The effective conductivity (λ_{eff}) can be calculated by the equation below, where the total heat transfer (Q) is obtained by Fluent simulation.

$$\lambda_{eff}(T) \simeq \frac{Q}{T_1 - T_2} \qquad (1)$$

Where, T_1 is hot side temperature, and T_2 is cold side temperature. T is block average temperature, that is, the mean value between T_1 and T_2.

2.2 Fluent Modeling

The calculation domain for Fluent is shown in Fig. 2, which is constructed with about 220,000 hexagonal meshes. The portion where the poison rods are inserted, assumed as fuel block and details of the dowel part is neglected. The top and the bottom surfaces is treated as symmetry and the left and the right hand side surface of the calculation domain to be set as wall boundary as shown in Fig. 2. DO radiation model embedded in Fluent is used for calculation. To attain a profile of effective conductivity according to the variation of (mean) temperature, the heat transfer calculations are repeated on various conditions of temperature matrix.

The components involving on the heat transfer of the fuel block are helium, graphite block (Graphite 451), and fuel compact. The heat transfer in the cavity of the coolant holes and the cavity between the fuel blocks is activated through the fluid helium. The variations of density and conductivity of helium can not be ignored under the core pressures 7 MPa, so these variations are considered. As the heat capacity of helium is not so sensitive to the temperature, it is assumed as constant value 5,190 J/kg-K. The variations of heat capacity and the conductivity to the temperature for the graphite and the fuel compact are also considered. But the density of the graphite and the fuel compact is assumed having constant value 1,740 and 10,000kg/m^3, respectively.

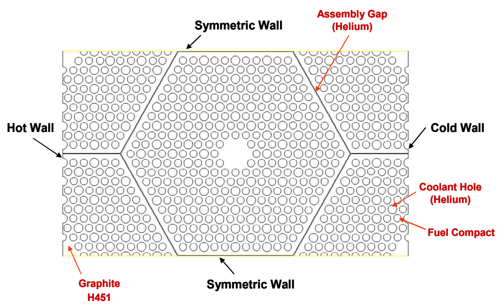


Fig. 2 Calculation domain for Fluent

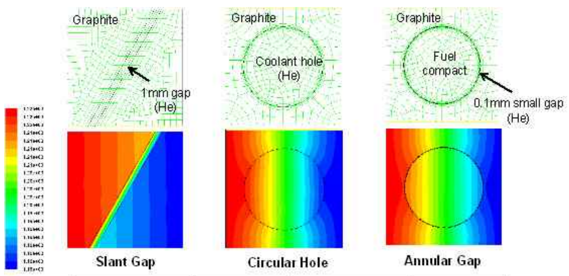
2.3 Calculation Results

From a radiation heat transfer point of view, the whole fuel block can be divided into three types of unit cells, that is, a slant-gap cell occupying on the block boundaries, circular-hole cell including the coolant path, and annular-gap cell where fuel compact located.

Accordingly, in advance to simulate the complicated whole fuel block, to investigate the characteristics of the radiation heat transfer for each unit cell is needed. Fig. 3 shows the calculation results of heat transfer for three types of unit cell. In the slant gap, the portion of the radiation heat transfer to the entire heat transfer is about 38% that is larger than that of circular cavity cell value, 11%. In other words, the effect of radiation heat transfer in the slant gap is more critical than that of annular gap. Contrarily, in an annular gap, the effect of radiation heat transfer is very low, controlled lower than 1 %. Through the unit cell study, we can assume that the portion of radiation heat transfer to the entire heat transfer of the fuel block will be about 10 to 20%.

The calculated effective conductivity for the whole fuel block, when disabling the radiation, is 13% lower than that of full modeling. This is well agreed with the estimation of the portion of radiation heat transfer to the entire heat transfer through the unit cell study. The effective conductivity is not seriously affected by the discretization and pixel setting of the radiation model.

The effective conductivity is mainly determined by the mean temperature of the whole temperature field, and the effect of the temperature deviation between hot and cold side is negligible.



Case	Slant Gap	Circular Hole Fluid-inside (Helium)	Annular Gap
Total Heat Transfer Rate[Q, W]	462	720	817
Total Radiation [W]	176.8	81	4
Rad./Total H. T.	**0.38**	**0.11**	**0.005**

Radiation Heat Transfer

Fig. 3 Comparison of Heat Transfer Characteristics for the Unit Cell

Fig. 4 shows the distribution of effective conductivity (λ_{eff}) and the distribution of effective conductivity normalized by the graphite conductivity (λ_{eff}/K_{H451}) according to the fuel block mean temperature. The effective conductivity is slightly increasing in accordance with the rise of the mean temperature of the fuel block. The effective conductivity normalized by the graphite conductivity reaches 0.47 when the reference mean temperature of the fuel block is 1,200K. The curve fitting of the effective conductivity expressed by the second order function is shown in equation (2) as below.

$$\lambda_{eff} = 14.38461 - 0.01105T_m + 1.03939*10^{-5}T_m^2 \quad (2)$$

The effective conductivity estimated by Fluent is similar to that value used in GAMMA+ calculation [2] but the trend has a little difference. Comparing Fluent with the analytical solution of the effective conductivity generalized by the void fraction [3], the trend shows similar between the two cases.

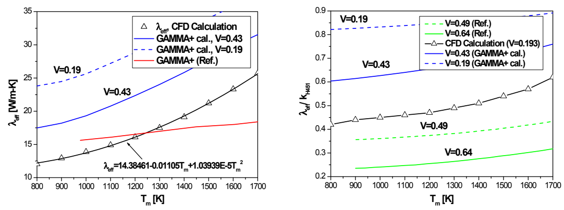


Fig. 4 Distribution of effective conductivity according to the fuel block mean-temperature

3. Conclusions

The full modeling of the actual fuel block has been performed by Fluent and the fraction of radiation heat transfer to the entire heat transfer of the fuel block is estimated about 13%. The effective conductivity is not seriously affected by the setting of the radiation model. The effective conductivity is mainly determined by the mean temperature of the whole temperature field, and the effect of the temperature deviation between hot and cold side is negligible. The effective conductivity is slightly increasing in accordance with the rise of the mean temperature of the fuel block and the effective conductivity normalized by the graphite conductivity reaches 0.47 when the reference block mean temperature is 1,200K. The effective conductivity estimated by Fluent is similar to that value used in GAMMA+ calculation but the trend has a little difference. Comparing the Fluent predictions with the analytical solutions, the trend of the effective conductivity shows similar between the two.

Acknowledgements

This work was supported by Nuclear R&D Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

REFERENCES

[1] Lee et al, "Final Report of the Development of Very High Temperature Reactor Design Technology, KAERI, KAERI/RR-2753/2006, pp. 284-285, May 2007

[2] Ji Su Jun, Calculation Note, "Thermo-Hydraulic Analysis for the Candidate Core of PMR 200MWt Demo-Plant by Utilizing GAMMA+ Code," NHDD-RD-CA-09-004, March 2009.

[3] J-C Han, M. J. Driscoll and N. E. Todreas, "The Effective Thermal Conductivity of Prismatic MHTGR Fuel," MIT-ANP-TR-005, Sept. 30, 1989.