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# CFD Analysis of the Fuel Temperature in High Temperature Gas-Cooled Reactors

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## 1. Introduction

High temperature gas-cooled reactors (HTGR) have received a renewed interest as potential sources for future energy needs, particularly for a hydrogen production. Among the HTGRs, the pebble bed reactor (PBR) and a prismatic modular reactor (PMR) are considered as the nuclear heat source in Korea's nuclear hydrogen development and demonstration project. PBR uses coated fuel particles embedded in spherical graphite fuel pebbles. The fuel pebbles flow down through the core during an operation. PMR uses graphite fuel blocks which contain cylindrical fuel compacts consisting of the fuel particles. The fuel blocks also contain coolant passages and locations for absorber and control material. The maximum fuel temperature in the core hot spot is one of the important design parameters for both PBR and PMR.

The objective of this study is to predict the fuel temperature distributions in PBR and PMR using a computational fluid dynamics(CFD) code, CFX-5. The reference reactor designs used in this analysis are PBMR400 [1] and GT-MHR600 [2].

## 2. Numerical Methods

### *2.1 CFD Model*

The GT-MHR (PMR) reactor core is loaded with an annular stack of hexahedral prismatic fuel assemblies, which form 102 columns consisting of 10 fuel blocks stacked axially in each column. Each fuel block is a triangular array of a fuel compact channel, coolant channel and a channel for a control rod. Only 1/6 of the two fuel channels and a single coolant channel are modeled using the symmetry of the fuel block. Diameters of the fuel channel and the coolant channel are 12.7mm and 15.9mm, respectively. It is noted that there is a 0.125mm gap between the fuel compact and the fuel channel. The central distance between the fuel channels and the coolant channel is 18.85mm. The height of each block is 793mm.

Fig. 1 shows the 1/6 CFD model with the grid to calculate the temperature distributions for the PMR fuel block. Total number of elements for the 10-block model is 282,200 with the grid sizes of 0.06mm to 0.8mm in the lateral direction and 16mm in the axial direction, respectively.

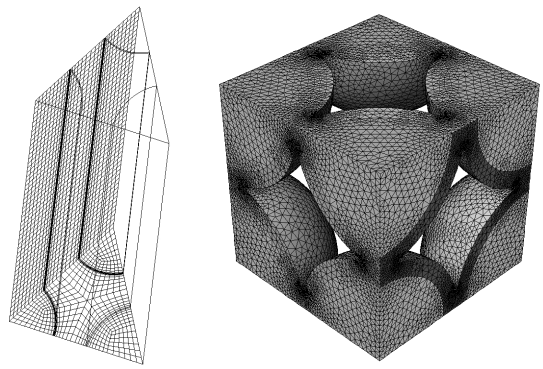

Figure 1. CFD models with grids for PMR and PBR.

The PBMR core consists of approximately 450,000 fuel pebbles that are stacked in a graphite reflector structure. A typical fuel pebble consists of a fueled region surrounded by a thin unfueled region at the surface. The fueled region consists of a graphite matrix surrounding several tens of thousands of fuel particles. The pebble diameter is 60mm with the 5mm unfueled layer. An array of 2x2 pebbles (Fig. 1) is simulated here to predict the temperature distribution in the pebble. Approximately 218,000 nodes are used in this model.

### *2.2 Boundary Conditions*

The uniform cooling flow and constant pressure are assumed respectively at the inlet and the exit of the coolant channel in the PMR fuel block. Symmetric conditions are used at the side boundaries of the PMR model. Constant heat generation rates in the fuel channels of each block are given.

For the 2x2 pebble model, the fully developed flow condition and constant pressure are applied respectively at the inlet and outlet boundaries in a streamwise direction. A constant pressure is assumed at the lateral boundaries where an inflow as well as an outflow are allowed. Constant heat generation rates in the fueled region of the pebbles are given.

### *2.3 Design Operating Conditions*

Helium at the inlet pressure of 7 MPa is used as coolant for both PMR and PBR. The helium mass flowrate per the PMR coolant channel is 0.02126 kg/s and the core average inlet/outlet helium temperatures are 490 °C and 950 °C. The average power density distribution (Qavg=31.23 MW/m$^3$) from a nuclear design is used here. The minimum and maximum power densities are 18.4 and 38.3 MW/m$^3$ for fuel blocks 4 and 10, respectively. For the PBR case, the bulk velocity and temperature of the helium in the hot core region are known to be approximately 15.8 m/s and 1047 °C, respectively. The heat generation rate in the hot pebbles is 14.75 MW/m$^3$.

The physical properties of the helium are given as a function of the temperature at the operating pressure of 7 MPa. The thermal conductivities of the fuel compact, fuel gap, pebble and graphite also vary with the temperature.

## 3. Results and Discussions

Figure 2 shows the calculated temperature distribution at the exit of the PMR core, GT-MHR600. The bulk exit temperature of the coolant (helium) is 1036 °C. The maximum temperatures of the fuel and graphite are 1128 °C and 1097 °C, respectively. The lateral temperature drops are estimated as 20, 16, 9 and 47 °C in the regions of the fuel compact, fuel gap, graphite and coolant, respectively. Figure 3 shows the axial variation of the temperature in the fuel, graphite and coolant. The temperature difference between the coolant and the fuel increases in a high power block.

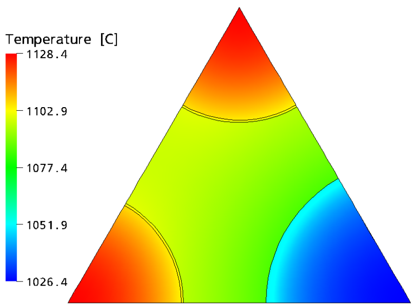


Figure 2. Temperature distribution at the exit of the GT-MHR600 core for Qavg=31.23 MW/m$^3$ and m=0.02126 kg/s.

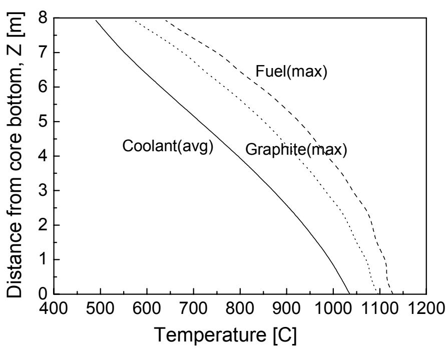


Figure 3. Axial temperature distribution in the GT-MHR600 core for Qavg=31.23 MW/m$^3$ and m=0.02126 kg/s.

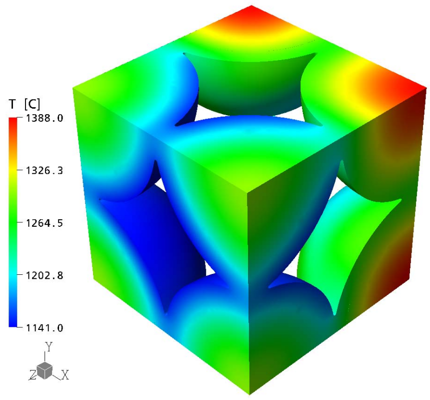


Figure 4. Pebble temperature distribution in the PBMR400 core for the pebble power density of 14.75 MW/m$^3$.

Figure 4 shows a bird's-eye view of the pebble temperature distribution in the PBMR400 core. The pebble center temperatures are 1388 °C and 1298 °C for the upstream and downstream pebbles, respectively. The average temperature drop in the pebbles is estimated as 148 °C. The higher temperature at the upstream pebble is predicted because the coolant flow is separated behind the upstream pebble.

## 4. Conclusion

The fuel temperature distributions for GT-MHR600 and PBMR400 were calculated using the recent core design data. The maximum fuel temperature for GT-MHR600 with an average core power density is predicted to have a margin of 122 °C for the design limit (1250 °C) during a normal operation. The temperature drop in the pebbles for PBMR400 is estimated as 148 °C and the maximum pebble temperature in the hot core region appeared to exceed the design limit. It is necessary to examine the effect of the coolant flow conditions at the side boundaries and a staggered pebble array for the PBR model in the future.


## Acknowledgement

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## REFERENCES


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[2] N. Kodochigov, Y. Marova, N. Stepnoy, E. Glushkov, P. Fomichenko, Neutronic Features of the GT-MHR Reactor, Nuclear Eng. & Des., Vol. 222, pp. 161-171, 2003.