Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Thermal-Hydraulic Analysis of OECD Benchmark Problem for PBMR 400 Using MARS-GCR

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1. Introduction

The OECD benchmark problem for the PBMR 400[1] aims to test the existing methods for HTGRs but also develop the more accurate and efficient tools to analyse the neutronics and thermal-hydraulic behaviour for the design and safety evaluations of the PBMR. In addition, it includes defining appropriate benchmarks to verify and validate the new methods in computer codes.

The benchmark procedure is divided into two parts; 1) phase I, which includes the stand-alone steady state calculations (neutronics and thermal-hydraulics) and coupled steady state calculation, 2) phase II, which includes various transient calculations. Till now, stand-alone calculations for neutronics and thermal-hydraulics were performed with given cross-section and power density data, respectively. This paper includes the stand-alone thermal-hydraulic calculation results of MARS-GCR[2] with a given power density. Although a preliminary steady state calculation coupled with MASTER[3] was also performed, the calculation results will be released later.

2. System Layout and Boundary Conditions

The system modelling for PBMR 400 is very simple to avoid the complexities of analysis.

Figure 1 shows the general reactor layout and the coolant flow directions in (r, z) geometry and the flow characteristics are summarized in table 1.

Stagnant helium and air are defined between the side reflector, barrel and reactor pressure vessel (RPV) and between the RPV and reactor cavity cooling system (RCCS) respectively. No mass flow or convection should be calculated for these regions. This means that the only heat transfer mechanisms are thermal conduction and radiation across these two regions.

The material properties such as a thermal conductivity and specific heat are simplified to a representative constant value for all the graphite reflector regions. Contact conduction model of MARS-GCR is applied to the interfaces of adjacent heat structures and *Zehner-Schlünder* correlation[1] is used for the effective thermal conductivity of a pebble bed. The thermal conductivity in the porous regions where helium flow is defined is reduced according to the 20 % porosity except the pebble core which has 39 % porosity.

The isothermal condition is applied to the outer side of the RCCS wall, 20 ºC.

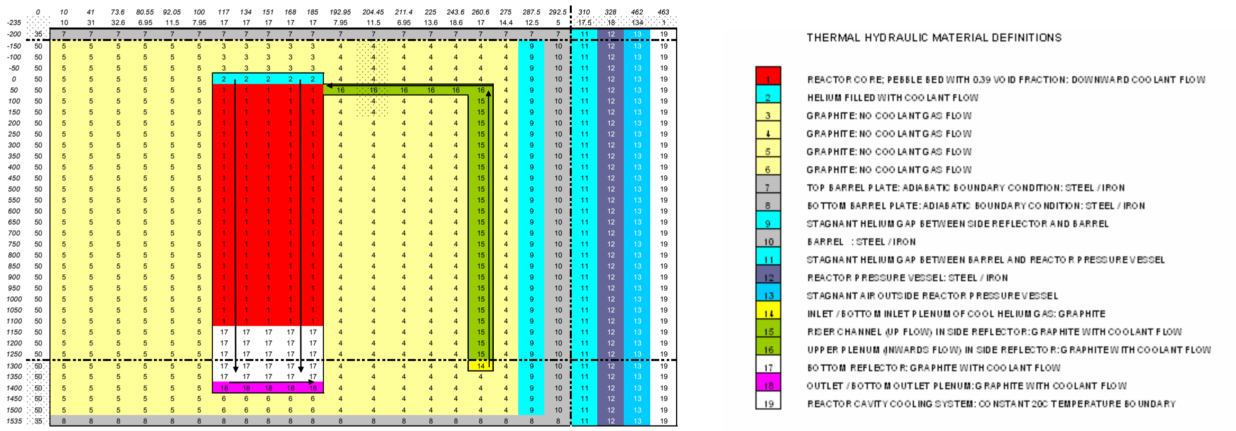

Figure 1. Thermal hydraulic material definitions

Table 1. Main flow parameters

Description	Unit	Value
He inlet / outlet temperature	ºC	500 / Calculated
Total inlet mass flow rate	kg/s	192.7
Inlet / Outlet Pressure	kPa	9000 / Calculated
Coolant flow is into inlet plenum (← 14), up into the He flow skirt (↑ 15), into top plenum (← 16); through the core and void (↓ 1 ←2); through porous bottom reflector (↓ 17); into bottom / outlet plenum (→18).		
No bypass flow or special coolant flow paths (all the mass flow through the pebble bed)		None

3. Thermal-Hydraulic Calculation Results

3.1 Core Power Data

A given power density used in the calculation is shown in figure 2. As shown in the figure, the power density of innermost core (ring 1) is greater than those of the other regions, whereas the coolant flow rate is the smallest according to the fraction of cross sectional area. For the axial direction, the power shape is somewhat top-skewed.

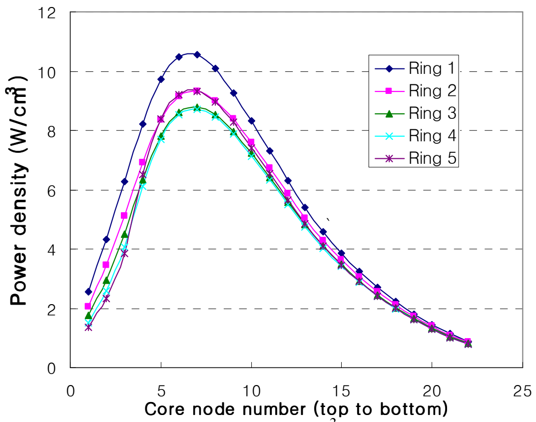

Figure 2. Power density (W/cm^3) for fuel meshes

3.2 Thermal-Hydraulic Results with MARS-GCR

With a given power shape, the thermal-hydraulic stand-alone steady state calculation was performed using MARS-GCR.

Figure 3 shows the radial temperature profile in the steady state. The temperature of inner core ring is higher than that of outer core and the temperature difference is about 150 ºC. This difference results from the mismatch between the power density and coolant mass flux along the axial direction. Generally, frictional pressure drop increases with the temperature rise because the viscosity of helium increases with the fluid temperature. As a result, the coolant flow rate decreases in the innermost core ring where the fluid temperature is highest. In addition, as shown in the figure 5, the axial coolant flow profile in the core region is nearly flat because the radial flow in the core is little except the top and bottom core. It means that the thermal mixing between the hotter and colder region is very low and results in the higher temperature difference.

At the core bottom, interfaced with the top of bottom reflector, the coolant tends to flow into the outer side because the outlet boundary volume is connected to the outer side of the outlet plenum and the axial pressure drop at this region increases.

4. Conclusion and Further Works

A thermal-hydraulic calculation of OECD benchmark problem for PBMR 400 has been performed with MAR-S-GCR and it is found that the results of the T/H standalone calculation are reasonable.

In order to quantify the applicability of MARS-GCR to HTGRs, however, a comparison with the other code systems results, as well as MARS-GCR/MASTER coupled calculation, should be performed.

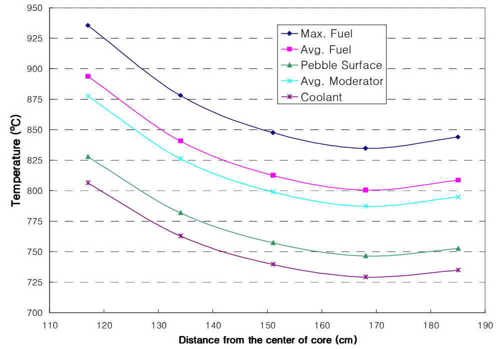

Figure 3. Radial temperature profile

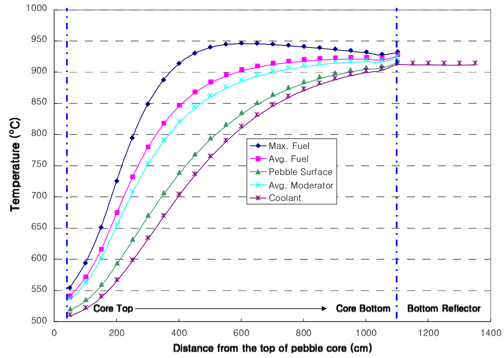

Figure 4. Axial temperature profile

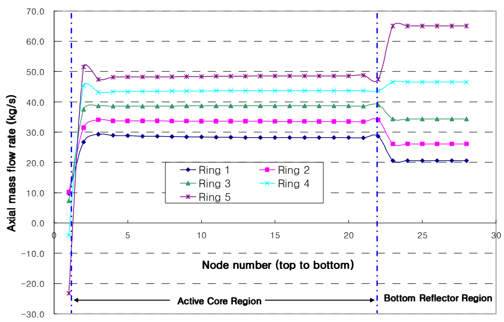

Figure 5. Axial coolant flow profile

ACKNOWLEDGEMENTS

This work has been performed as a part of the Nuclear R&D Program supported by the Ministry of Science and Technology (MOST) of the Republic of Korea.

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