A Sub-channel Analysis of a VHTR Fuel Block with Tin Gap-Filler

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1. Introduction

In the Nuclear Hydrogen Development and Demonstration (NHDD) project, two types of VHTRs (Very High Temperature Reactors), prismatic or pebble bed, are under investigation as the nuclear heat source for hydrogen production. In general, the targeted coolant outlet temperature of VHTR is 950~1000˚C and the maximum allowable fuel temperature is 1250˚C during the normal operation. In the case of the prismatic reactor (PMR), conventional fuel designs result in a small margin in the maximum fuel temperature [1]. This is one of the biggest demerits of the prismatic type

In this paper, a technique of lowering the maximum fuel temperature is suggested. The PMR fuel assembly is comprised of many coolant holes and fuel channels as shown in Figure 1. Cylindrical fuel compacts are stacked inside the fuel channel. Consequently, there should be a physical gap between the fuel compact and graphite block, which is filled with the He gas in the conventional design. The heat transfer coefficient of the He gap is very poor, and this increases the fuel temperature substantially. In the proposed design measure, the gap is filled with a liquid metal, tin (Sn) that has a very high thermal conductivity. The effects of tin in the gap with gap distance variation in the viewpoint of thermal hydraulics are quantitatively discussed. Also, the effects of the variations of the axial power distribution are discussed.

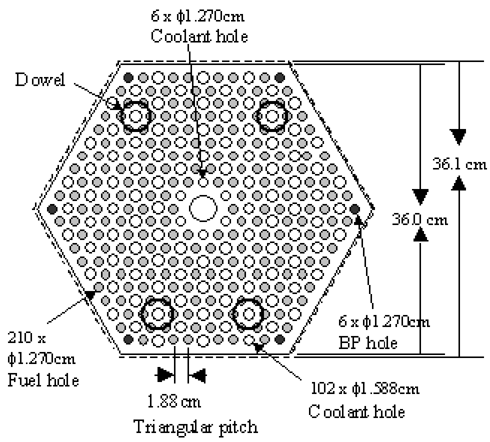

Figure 1. Cross sectional view of the PMR fuel assembly

2. Numerical Approach

All the geometry and dimensions used in the thermal hydraulic analyses are based on the standard design of the PMR fuel assembly [2]. Figure 2 shows the computational domain used in thermal hydraulic analyses schematically.

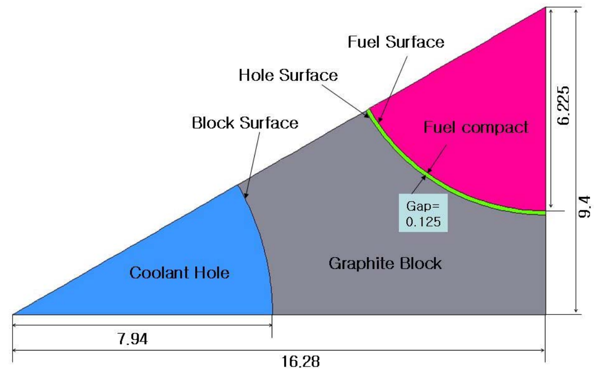

Figure 2. Computational domain of unit sub-channel.

The core coolant is helium gas and the active core height is 8 m. The helium coolant flows downward in the core. Table 1 shows the boundary condition used in the thermal hydraulic analyses.

Table 1. Boundary conditions in the sub-channel analyses

Coolant Flow rate (kg/s)		229.3
Inlet Velocity (m/s)		24.86
Coolant Inlet Temperature (ºC)		491
Reference Pressure (atm)		70
Fuel Compact Power Density (MW/m^3)	0.125	30.00
	0.188	30.61
Designed outlet Temperature (ºC)		1000

The thermal-hydraulic analyses are performed using the CFX5.7 code [3]. In the thermal hydraulic analyses, the standard k-ε turbulence model was used to predict the turbulent flow characteristics, and the logarithmic law-of-the-wall to predict the near-the-wall characteristics

3. Results

3.1 Effect of tin gap-filler

Figure 3 shows cross-sectional temperature distribution from fuel compact centre to coolant hole centre. With a 0.125 mm gap distance, the tin filler lowers temperatures at the fuel compact surface and center by ~24˚C. With a 0.188 mm gap distance, the maximum temperature of fuel compact centre with Tin gap-filler is 36˚C lower than that of the He gap-filler.

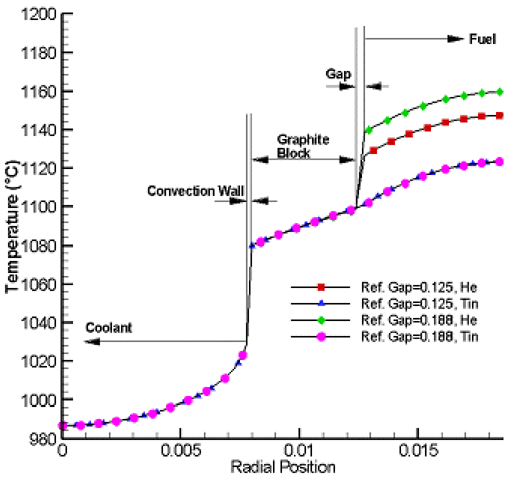

Figure 3. Effects of tin on the radial temperature distribution.

Table 2. The results of the thermal-hydraulic analysis.

Gap distance (mm)	0.125		0.188	
Gap Filler	He	Tin	He	Tin
Outlet Mean Velocity (m/s)	44.15	44.15	44.15	44.15
Pressure Drop (Pa)	22218	22218	22219	22219
Bulk Outlet Temp. (℃)	1002	1002	1002	1002
Max. Bulk Temp. (℃)	1037	1037	1037	1037
Max. Block Surf. Temp	1080	1080	1080	1080
Max. Hole Surf. Temp	1107	1105	1107	1105
Max. Fuel Surf. Temp	1128	1106	1140	1106
Max. Fuel Temp	1148	1124	1160	1124
Fuel Temp Diff. (Tin – He)	-24		-36	
Temp Diff. (in Gap)	22	0.24	33	0.35

3.2 Effecst of the variation of the axial power distribution

Figure 4 shows the axial power distributions used in thermal hydraulic analyses. Impacts of the axial power distributions on the fuel temperature were evaluated. Note that two average power densities, 35MW/m^3 and 40.25MW/m^3, were considered.

For the picked power density (40.25MW/m^3), Fig. 5 shows the axial temperature distributions in the top-skewed power distribution. The maximum temperature of the fuel compact is 1210˚C that is about 40˚C lower than that of the design limit, that is, 1250˚C. In the same case with the He gap-filler, the maximum temperature of fuel compact is 1228˚C that is about 18˚C higher than that of the Tin gap-filler. In the top-skewed case, the power density at the core bottom zone is very low. Thus the effect of the tin is not very large. However, it was observed that the impact of tin was substantially higher in other cases.

4. Conclusions

The calculation results show that the maximum fuel temperature in the prismatic type VHTR can be lowered by filling the gap between the graphite block and fuel compact with liquid tin. The tin gap-filler lowers the fuel temperature by 18~30˚C for the nominal gap size, depending on the power density, without compromising any thermal-hydraulic performance of the fuel blocks. In the actual core, the gap size may increase a little, in which the effect of tin would be enhanced.

Also, it was confirmed that a top skewed power distribution in the prismatic type VHTR is favorable form the viewpoint of the fuel temperature.

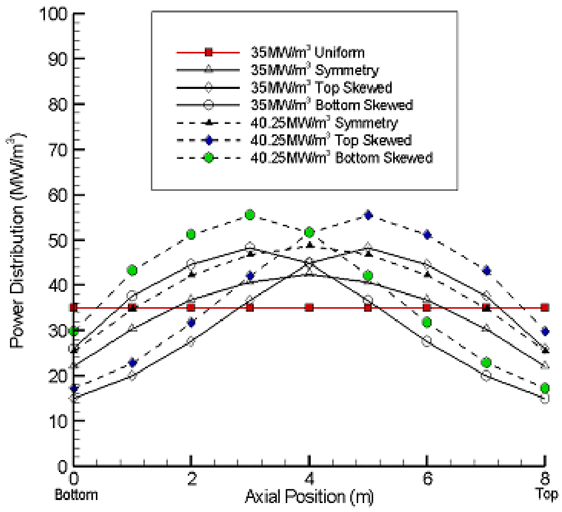

Figure 4. Axial power distribution of the fuel compact

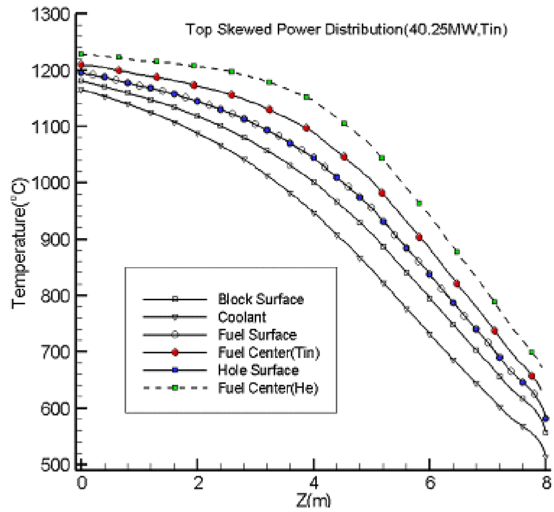

Figure 5. Axial temperature distribution in sub-channel

REFERENCES

[1] P.E. MacDonald, et al., INEEL/EXT-03-00870, Sep. 2003.

[2] Gas Turbine-Module Helium Reactor (GT-MHR) Conceptual Design Description Report, GA Project No. 7658, July 1996

[3] CFX 5.7 Manuals, ANSYS Incorporated, 2004