PRELIMINARY EVALUATION OF COOLANT TEMPERATURE DISTRIBUTION IN HYPER FUEL ASSEMBLIES

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ABSTRACT

Progression of core design of HYPER into the final design stage requires accurate calculation of thermal hydraulic behavior of the assemblies in the reactor core. However, such a type of detailed calculations for Pb-Bi cooled subcritical reactors have not been made before because most of Pb-Bi (or Pb) cooled reactors proposed are still too conceptual and schematic. In order to advance thermal hydraulic knowledge of HYPER core, detailed coolant temperature distributions were calculated for the preliminary HYPER design using a subchannel analysis code, SLTHEN. Two cases were considered in the present work. At first, subchannel analysis was performed for single fuel assembly to check the feasibility of modifications of SLTHEN and to assess the coolant mixing and heat transfer between subchannels. Next seven assemblies were considered to investigate heat transfer behavior between assemblies. The SLTHEN calculations with various turbulent mixing parameters show that the maximum cladding temperature within an assembly is not largely affected by turbulent mixing and interassembly heat transfer in HYPER conditions. Based on the results of the present calculations, it is judged that the modified SLTHEN can reasonably predict the coolant temperature distributions in Pb-Bi cooled bare rod assemblies and is very useful tool for analyzing thermal hydraulic behavior of the HYPER core.

1. INTRODUCTION

Incineration of long-lived radionuclides, in particular in an accelerator driven system (ADS), is considered to be one of the most favorable solutions of nuclear waste. KAERI (Korea Atomic Energy Research Institute) is developing the ADS named HYPER (HYbrid Power Extraction Reactor) [1]. About 258kg of transuranic (TRU) is expected to be transmuted in the HYPER system for a year and to produce 1000 MW thermal energy. Pb-Bi is used for the coolant and target material simultaneously. Currently major design concepts of HYPER are fixed and the design optimization of subcritical core is going on.

Naturally, progression of core design of HYPER into the final design stage requires accurate calculation of thermal hydraulic behavior of the assemblies in the reactor core. However, such a type of detailed calculations for Pb-Bi cooled subcritical reactors have not been made before because most of Pb-Bi (or Pb) cooled reactors proposed are still too conceptual and schematic. In order to advance thermal hydraulic knowledge of HYPER core, detailed coolant temperature distributions were calculated for the preliminary HYPER design with bare rods assemblies based on subchannel approach. A subchannel analysis code, SLTHEN [2], developed for sodium cooled wire wrapped assemblies was modified to analyze the Pb-Bi cooled bare rod assemblies and applied to HYPER conditions. Two cases were considered in the present work. At first, subchannel analysis was performed for single TRU assembly to check the feasibility of modifications and to assess the coolant mixing and heat transfer between subchannels. Next seven assemblies were considered to investigate heat transfer between assemblies.

2. SUBCHANNEL ANALYSIS AND RESULTS

The SLTHEN code was originally developed for subchannel analysis of sodium cooled wire wrapped assemblies based on ENEGRY model. Since the original SLTHEN code cannot be directly applied to HYPER using Pb-Bi coolant, some modifications of the SLTHEN code were made. The properties of Pb-Bi were added and pressure drop correlations, flow spilt and turbulent mixing models were modified to consider bare rod conditions.

The design parameters of HYPER for the present work are shown in Table I. The design characteristics of HYPER are similar to the existing sodium cooled reactors in many ways. HYPER uses triangular lattice for fuel rod and hexagonal duct. But wire spacers are not suitable for HYPER since HYPER adopts a loose lattice (P/D = 1.48).

Table I. Design parameters of HYPER for the present work

Parameter	Values
Core :	
Core thermal power [MWth]	1000
Coolant	Pb-Bi eutectic
System operating temperature [℃]	340 - 510℃
Cooling type	forced convection
Active core height [m]	1.6
Fuel (TRU) assembly :	
Assembly pitch [cm]	16.13
Inter assembly gap thickness [cm]	0.3
Duct inside flat to flat distance [cm]	15.01
Duct wall thickness (cm)	0.26
Rods per assembly	217
Nominal linear power generation [W/m]	12152.6
Nominal assembly mass flow rate [kg/s]	173.6 kg/s
Spacer type	bare rod
Fuel rod :	
Fuel rod arrangement	triangular
Active height (cm)	160
Outer diameter (cm)	0.67
Pitch/diameter	1.48
Cladding thickness (cm)	0.068

2.1 CASE 1: SINGLE FUEL ASSEMBLY

Subchannel analysis was performed for single TRU fuel assembly to check the feasibility of modifications and to assess the coolant mixing and heat transfer between subchannels. Axial power profile of the reference assembly is assumed as chopped cosine shape having peaking factor of 1.2 in the present work. Single fuel assembly of HYPER was modeled as 438 subchannels including interior, edge, corner channels as shown in Fig. 1.

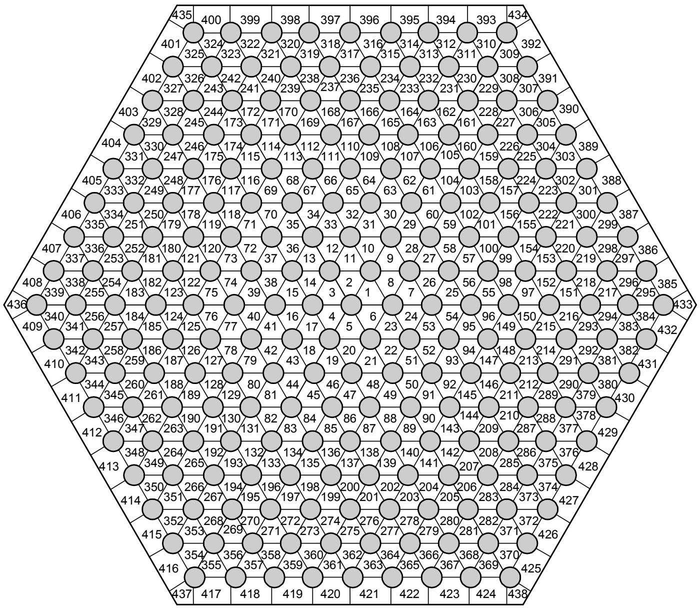

Figure 1. Subchannels of single fuel assembly of HYPER.

In subchannel analyses, turbulent mixing is considered as the most important parameter affecting the coolant mixing and heat transfer between subchannels. In the SLTHEN code, turbulent eddy diffusivity (ε_H) is used to model a phenomenon of turbulent mixing. For the HYPER design conditions with bare rod assembly, typical value of ε_H for HYPER conditions is expected as ~10^{-5} m^2/s. The turbulent eddy diffusivity calculated by various models for HYPER design conditions is shown in Table II.

Table II. Turbulent eddy diffusivity calculated by various models for HYPER design conditions

Correlations	Rogers-Tahir [3]	Dwyer [4]	Nikuradse [5]	Rogers-Rosehart [6]
ε_H (m^2/s)	1.431×10^{-5}	8.121×10^{-6}	6.769×10^{-5}	4.0×10^{-5}

Figure 2 shows the coolant outlet temperature distributions in the reference assembly of HYPER calculated by the SLTHEN code. The calculations were made with wide range of the turbulent eddy diffusivity to investigate its effect. It can be seen that there is a large temperature difference (~60 ^oC) within an assembly although radially uniform power profile is assumed across the assembly. Compare to the average coolant outlet temperature of 510 ^oC, the maximum coolant outlet temperature was predicted higher than the average one by ~10 ^oC. Figure 2 also shows that temperature gradient between the center and edge channels is reduced with the increase of turbulent mixing. This means that the modified SLTHEN code can reasonably simulate heat transfer between subchannels. As shown in Table II, the typical value of ε_H for HYPER conditions is expected as

~10^{-5} m^2/s. Therefore, it can be seen that maximum cladding temperature within an assembly is not largely affected by turbulent mixing between subchannels so long as HYPER does not adopt mixing promoters such as mixing vane or wrapper wire.

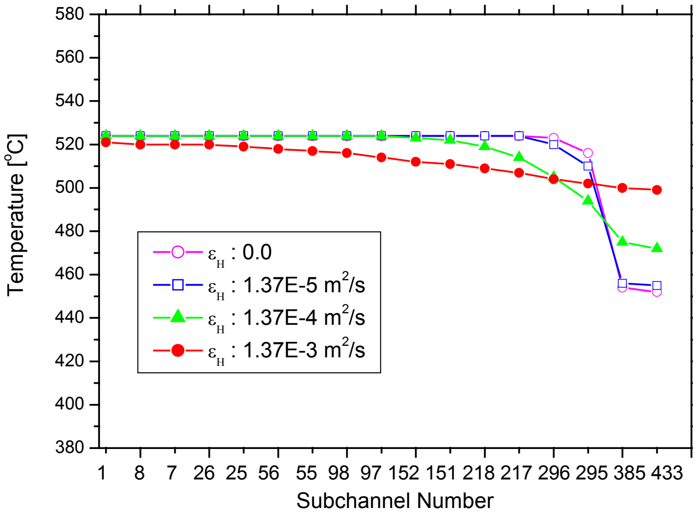

Figure 2. Coolant outlet temperature distribution within single assembly of HYPER.

2.2 CASE 2: SEVEN ASSEMBLIES

Results of single assembly could be unrealistic since it neglects interassembly heat transfer. It is desirable to understand quantitatively how the interassembly heat transfer affects the coolant temperature distribution. In order to investigate effect of heat transfer between assemblies, seven fuel assemblies having three different assembly powers were considered as shown in Fig. 3.

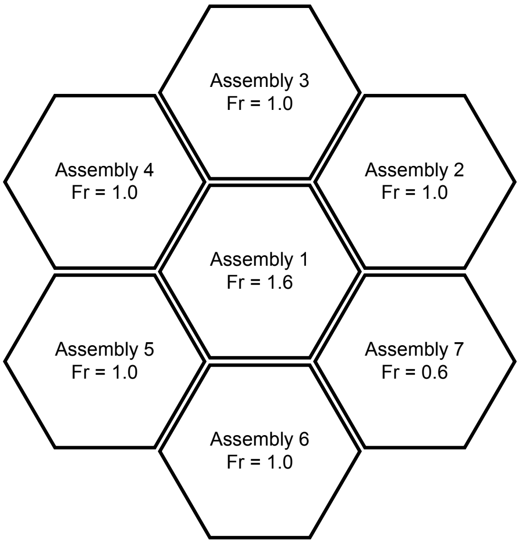

Figure 3. Seven assemblies considered in the present work.

For axial power profile, chopped cosine shape having peaking factor of 1.2 is assumed for all assemblies.

Before assessing the effect of interassembly heat transfer, SLTHEN calculation was performed for seven assemblies with the assumption of no heat transfer between assemblies. The results are summarized in Table III and it is confirmed that the results are the same with the single assembly case.

Table III. Summary results of SLTHEN calculation for seven assemblies with no heat transfer between assemblies

Assembly	1	2	3	4	5	6	7
Ave. Exit Coolant Temp.(°C)	612.0	510.0	510.0	510.0	510.0	510.0	442.0
Peak Coolant Temp. (°C)	634.8	524.2	524.2	524.2	524.2	524.2	450.5
Maximum Cladding Temp. (°C)	654.7	536.7	536.7	536.7	536.7	536.7	458.0

Figure 4 shows the coolant outlet temperature distributions of three assemblies having different assembly powers calculated by the SLTHEN code. Thanks to large temperature gradient at the interfaces of the assemblies, effect of the turbulent mixing is boosted compare to the single assembly case. It can be seen, however, active heat transfer between subchannels near the interfaces is not propagated enough to decrease the maximum coolant temperatures of the assemblies.

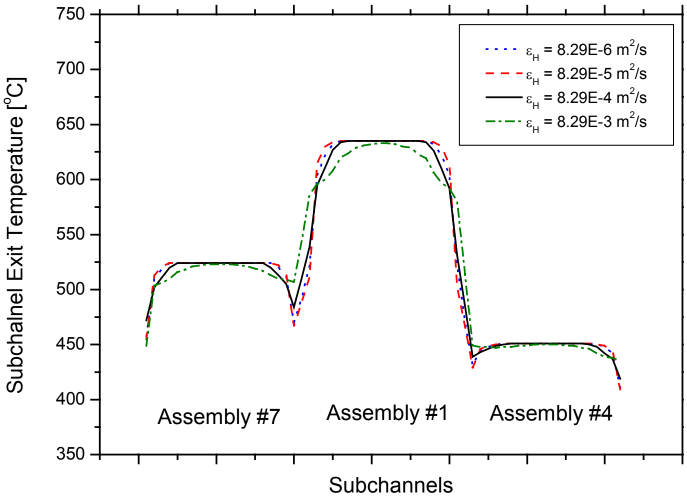

Figure 4. Coolant outlet temperature distributions of three assemblies having different assembly powers.

3. CONCLUSIONS

In the present work, detailed coolant temperature distributions using subchannel analysis were predicted for fuel assemblies of HYPER. The existing SLTHEN code was modified and applied to single and seven assembly cases. The results of SLTHEN shows there exists ~60 °C of temperature difference within an assembly of HYPER and the maximum coolant outlet temperature is higher than the average one by ~10 ^{o}C for the reference assembly. And it also shows that the maximum cladding temperature within an assembly is not largely affected by turbulent mixing and interassembly heat transfer. Based on the results of the present calculations, it is judged that the modified SLTHEN can reasonably predict the coolant temperature distributions in Pb-Bi cooled bare rod assemblies and is very useful tool for analyzing thermal hydraulic behavior of the HYPER core.

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