PRELIMINARY THERMAL HYDRAULIC ANALYSIS OF HYPER FUEL ASSEMBLY USING MATRA

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Abstract

Sub-channel analysis of HYPER fuel assembly was performed using MATRA which is a sub-channel analysis code developed by KAERI based on COBRA-IV-I. The MATRA code was considered for comparison between codes and assessing the capability of overcoming the limitation of the SLTHEN code used in the previous works. Two types of single fuel assembly, i.e., average assembly and hot assembly were considered for the present work. The predicted peak cladding temperatures of the average and hot assemblies were 536.2°C and 653.8°C, respectively with the reference design parameters. The comparison of results obtained by two codes shows that there is a good agreement for the predicted thermal hydraulic behaviour. It is judged that MATRA as well as SLTHEN is a very useful tool for thermal hydraulic design of the HYPER core and MATRA can be used to make up for the limitation of SLTHEN.

Introduction

Incineration of long-lived radionuclides, in particular in an accelerator-driven system (ADS), is considered as one of the most favourable solutions of nuclear waste. KAERI (Korea Atomic Energy Research Institute) is developing the ADS named HYPER (HYbrid Power Extraction Reactor). [1] About 258 kg of transuranic (TRU) is expected to be transmuted in the HYPER system for a year and to produce 1 000 MW thermal energy. Lead-bismuth eutectic is used for the coolant and target material simultaneously.

Currently the core design of HYPER is under optimisation to get the best performance. Progression of core design of HYPER into the final design stage requires accurate calculation of thermal hydraulic behaviour of the assemblies. In the previous works, [2,3] the modified SLTHEN code was used for sub-channel analysis of HYPER fuel assemblies. Although the SLTHEN code is very useful for thermal hydraulic design of the HYPER core, it has some limitations. For example, only bare rods were modelled in the previous works. And a ductless fuel assembly, which is a meaningful option considered for HYPER, cannot be modelled with the SLTHEN code.

In the present work, sub-channel analysis of a HYPER fuel assembly was performed with the MATRA code. [4,5] MATRA is a sub-channel analysis code developed by KAERI based on COBRA-IV-I. [6] The MATRA code was considered for comparison between codes and assessing the capability of overcoming the limitation of the SLTHEN code.

Since the MATRA code is applicable to both water cooled reactors and liquid metal cooled reactors, the use of MATRA has some advantages. Table 1 summarises the comparison of two codes.

Table 1. **Comparison of SLTHEN and MATRA**

Item		SLTHEN	MATRA
Conservation equation		mass, energy	mass, momentum, energy
Analysis condition		steady state	steady state, transient
Model	fuel lattice	Triangular	triangular, rectangular
	assembly duct	with duct	with and without duct
	fuel rod spacer	bare rod, wire spacer	bare rod, wire spacer, grid spacer
	local deformation of geometry	Impossible	possible

In the present work, two types of single fuel (TRU) assembly, i.e., average assembly and hot assembly were considered for sub-channel analysis. The average assembly refers to an assembly having radial peaking factor 1.0 and the radial peaking factor of the hot assembly is chosen as 1.6. Axial power profiles of both assemblies are assumed as chopped cosine shape having peaking factor of 1.2. These assumptions on power profiles were conservatively made based on existing neutronic calculations. [1] Accurate power profiles will be obtained after more design optimisations of the HYPER core.

Sub-channel analysis

Table 2 shows major design parameters of HYPER used for the present analysis. Since lead-bismuth requires more pumping power than sodium, loose fuel lattice (P/D = 1.48) is adopted to reduce the pressure loss. Therefore, grid spacers are preferred. In the present work, pressure loss in grid spacers was considered but enhancement of turbulent mixing and cross flow by grid spacers was neglected.

According to Rheme's study, [7] the pressure loss by grid spacers can be estimated as:

$$\Delta P_s = C_v \left(\frac{A_s}{A_v}\right)^2 \frac{1}{2}\rho V^2 = K \frac{1}{2}\rho V^2$$

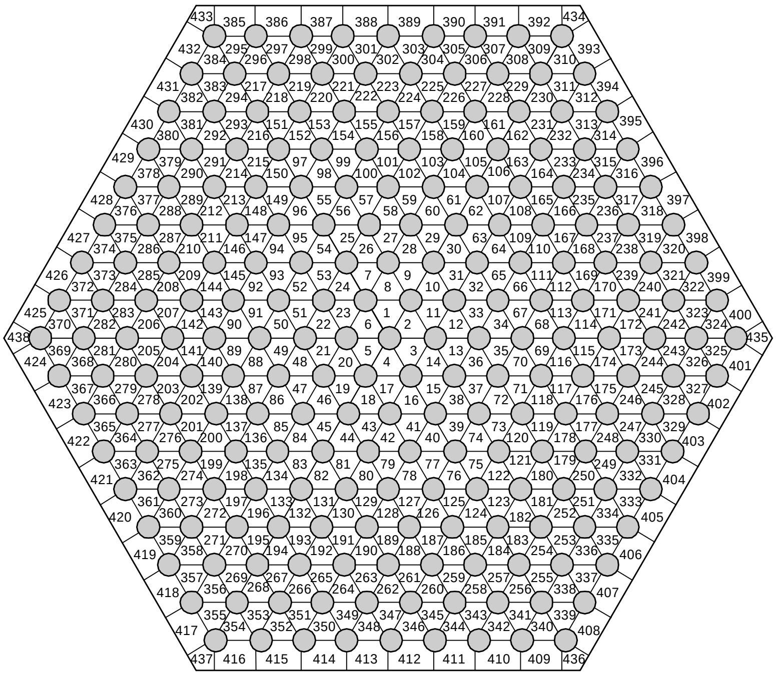
where, C_v is the modified drag coefficient, A_s is the projected frontal area of grid spacer, A_v is the unrestricted flow area away from grid spacer, ρ is the density of fluid, V is the average bundle fluid velocity, and K is the loss coefficient of grid spacer. The drag coefficient C_v is a function of the average bundle Reynolds number. But in a highly turbulent flow, the value of C_v becomes nearly constant value of 6.0. [7]

Figure 1 shows sub-channels in the single fuel assembly of HYPER. Three type of sub-channels, i.e., interior, edge, corner sub-channels can be seen. A total of 438 sub-channels were used to simulate single HYPER fuel assembly having 217 fuel rods. 50 nodes were assigned for the axial direction of a fuel rod.

Table 2. **Design parameters of HYPER for the present work**

Parameter	**Values**
Core:	
Core thermal power [MWth]	1 000
Coolant	Pb-Bi eutectic
System operating temperature [ˌ]	340-510ˌ
Cooling type	forced convection
Active core height [m]	1.6
Fuel (TRU) assembly:	
Assembly pitch [cm]	16.13
Duct inside flat to flat distance [cm]	15.01
Rods per assembly	217
Nominal assembly mass flow rate [kg/s]	173.6 kg/s
Spacer type	grid spacer
Fuel rod:	
Nominal linear power generation [W/m]	12 152.6
Fuel rod arrangement	triangular
Active height (cm)	160
Outer diameter (cm)	0.67
Pitch/diameter	1.48
Cladding thickness (cm)	0.068

Figure 1. **Sub-channels in 217 rods fuel assembly**



At first, MATRA calculations were performed with bare rod condition for the comparison with the previous results by the SLTHEN code. Table 2 shows the summary of MATRA results in case of bare rod condition. There is a good agreement between the results by two codes. MATRA predicted that the maximum coolant temperatures of the average and hot assemblies are 524.1°C and 635.2°C, respectively. These values are higher than the average coolant outlet temperatures by 14.11°C and 24.87°C, respectively. The peak cladding temperatures of the average and hot assemblies were predicted as 536.2°C and 653.8°C, respectively. The peak cladding temperature of the hot assembly exceeds the considered design limit 650°C by 3.8°C with the reference design parameters of the HYPER core.

Table 2. **The summary of the MATRA results in case of bare rod condition**

Item	Ave. assembly (Fz=1.2, Fr=1.0)		Hot assembly (Fz=1.2, Fr=1.6)	
	MATRA	SLTHEN	MATRA	SLTHEN
Velocity at channel inlet [m/s]				
Average	1.421	1.433	1.421	1.433
Interior	1.432	1.449	1.432	1.449
Edge	1.389	1.382	1.389	1.382
Corner	1.176	1.097	1.176	1.097
Pressure drop [kPa]	34.0	32.6	34.0	32.8
Average exit coolant temp. [°C]	512.0	510.0	610.3	612.0
Peak coolant temperature [°C]	524.1	524.2	635.2	634.8
Peak clad temperature [°C]	536.2	536.7	653.8	654.7

Bundle averaged coolant temperature distributions for average and hot assemblies are shown in Figures 2 and 3. They also show good agreement between calculations.

Figure 2. **Bundle averaged coolant temperature distribution in the average assembly**

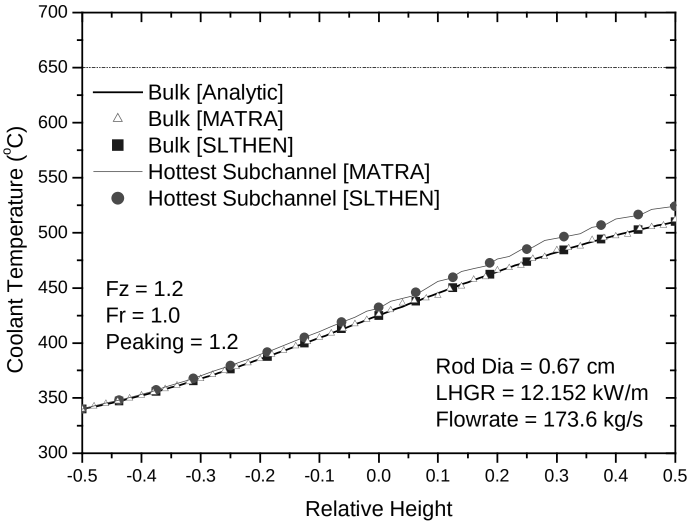
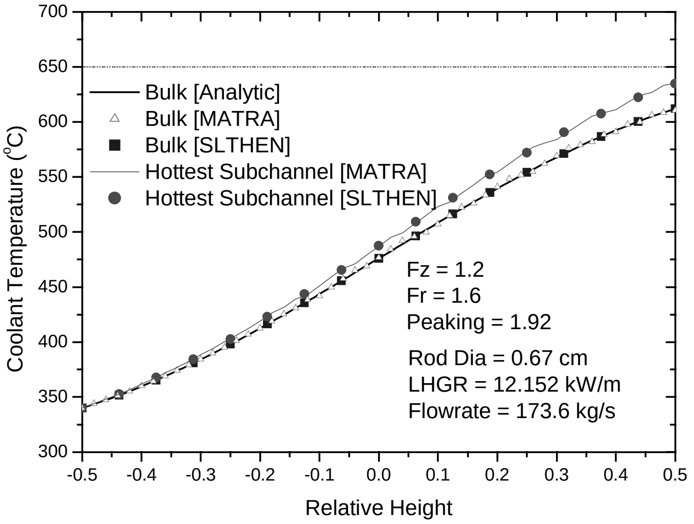
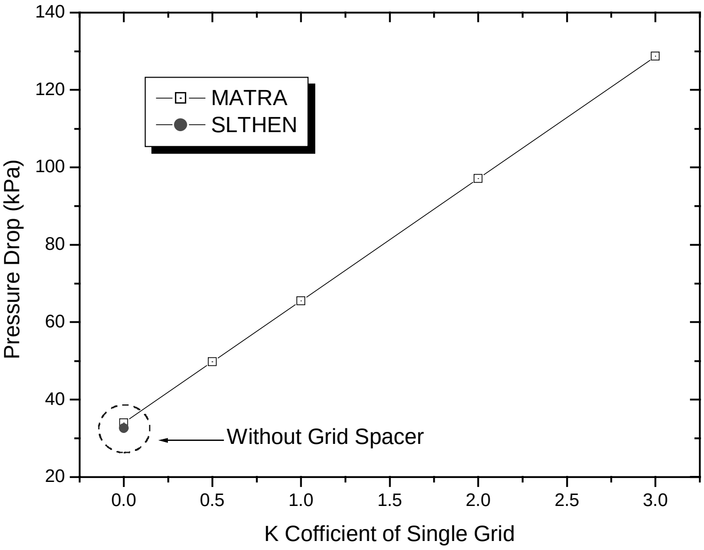


Figure 3. **Bundle averaged coolant temperature distribution in the hot assembly**



Grid spacers, which are adopted in HYPER, can be modelled without any code modifications of MATRA. Detailed calculations with grid spacers require detailed specification of grid spacers. Figure 4 shows the predicted pressure drop in the active region of HYPER core with 3 grid spacers. In HYPER core, flow is very turbulent (Re = 1.4×10^6) and the value of C_s can be close to 6.0. Assuming $A_s / A_v \approx 0.4$, the loss coefficient K of a grid spacer is ~1.0. In that case, ~70 kPa of total pressure drop is expected along the active length 1.6 m.

Figure 4. **Predicted pressure drop with 3 grid spacers**



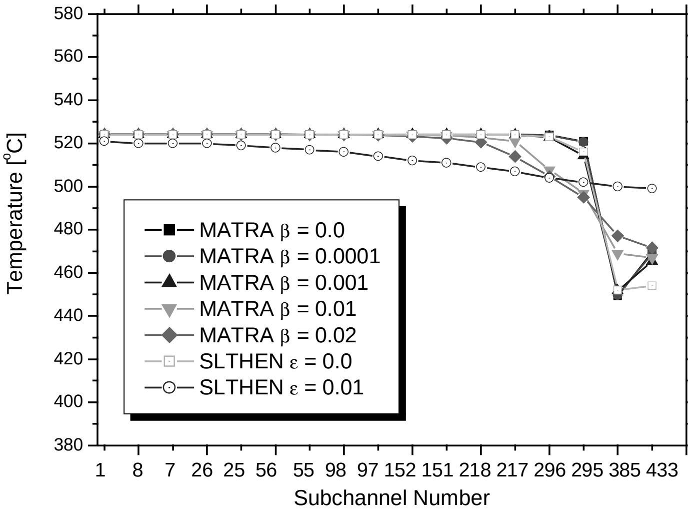
In sub-channel analysis, one of the most uncertain parameter is the turbulent mixing parameter. In MATRA, turbulent flow mixing is represented by β defined by

$$\beta = \frac{\text{Transverse mass flux}}{\text{Axial mass flux}} = \frac{W_{ij}^{*H}}{s_{ij}\overline{G}}$$

where W_{ij}^{*H} is the transverse mass flow rate per unit length across the gap between sub-channels i and j, s_{ij} is the gap width between sub-channels i and j, and $\overline{G}$ is the average axial mass flux. The value of β should be obtained by experiment for accurate calculations. As a rough estimate of β, Rogers and Tahir [8] correlation is used for the present work. Rogers and Tahir correlated the available literature for the various types of interacting sub-channels of design interest. The calculated β is 0.0025 in the HYPER condition. Compare to values of existing reactors, it is smaller because of low velocity of lead-bismuth and loose fuel lattice.

Figure 5 shows the effect of turbulent mixing parameter on the outlet temperature distribution. In the exit, ~75°C of temperature difference was predicted between sub-channels and larger value of β produces more active heat transfer between interior and edge channels. It can be seen, however, active heat transfer between sub-channels near the interfaces is not propagated enough to decrease the maximum coolant temperatures of the assembly. Since MATRA and SLTHEN define their mixing parameters in different ways (particularly, different length scales), direct comparison of results by two codes is not reasonable. But from Figure 5, it can be seen that the turbulent mixing parameter defined in MATRA gives smaller sensitivity.

Figure 5. **Effect of turbulent mixing parameter on outlet temperature distribution**



Conclusions

Sub-channel analysis of HYPER fuel assembly was performed with the MATRA code to provide comparisons between codes and to assess the capability of overcoming the limitation of the SLTHEN code used in the previous works. Two types of single fuel assembly, i.e., average assembly and hot assembly were considered. The predicted peak cladding temperatures of the average and hot assemblies were 536.2°C and 653.8°C, respectively with the reference design parameters. The comparison of results obtained by two codes shows that there is a good agreement for the predicted thermal hydraulic behaviour. With grid spacer model in MATRA, ~70 kPa of pressure drop was predicted along the active length of fuel rod with 3 grid spacers. Sensitivity study of the turbulent mixing parameter shows the predicted maximum coolant and cladding temperatures are not affected by the turbulent mixing parameter and the turbulent mixing parameter defined in MATRA gives smaller sensitivity than that defined in SLTHEN. Therefore, it is judged that MATRA as well as SLTHEN is a very useful tool for thermal hydraulic design of the HYPER core and MATRA can be used to make up for the limitation of SLTHEN.

Acknowledgements

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