Uncertainty Evaluation of the SFR Subchannel Thermal-Hydraulic Modeling Using a Hot Channel Factors Analysis

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1. Introduction

In an SFR core analysis, a hot channel factors (HCF) method is most commonly used to evaluate uncertainty. It was employed to the early design such as the CRBRP and IFR [1,2]. In other ways, the improved thermal design procedure (ITDP) is able to calculate the overall uncertainty based on the Root Sum Square technique and sensitivity analyses of each design parameters [3]. The Monte Carlo method (MCM) is also employed to estimate the uncertainties [4]. In this method, all the input uncertainties are randomly sampled according to their probability density functions and the resulting distribution for the output quantity is analyzed.

Since an uncertainty analysis is basically calculated from the temperature distribution in a subassembly, the core thermal-hydraulic modeling greatly affects the resulting uncertainty. At KAERI, the SLTHEN and MATRA-LMR codes have been utilized to analyze the SFR core thermal-hydraulics [5,6]. The SLTHEN (steady-state LMR core thermal hydraulics analysis code based on the ENERGY model) code is a modified version of the SUPERENERGY2 code, which conducts a multi-assembly, steady state calculation based on a simplified ENERGY model. The detailed subchannel analysis code MATRA-LMR (Multichannel Analyzer for Steady-State and Transients in Rod Arrays for Liquid Metal Reactors), an LMR version of MATRA, was also developed specifically for the SFR core thermal-hydraulic analysis.

This paper describes comparative studies for core thermal-hydraulic models. The subchannel analysis and a hot channel factors based uncertainty evaluation system is established to estimate the core thermofluidic uncertainties using the MATRA-LMR code and the results are compared to those of the SLTHEN code.

2. Methods and Results

2.1 Thermal-Hydraulic Analysis

For the core thermal-hydraulic analysis consisting of subassemblies with a subchannel of wire-wrapped rod bundle, the subchannel analysis is widely used. It characterizes the average mass, momentum, and energy balance in every subchannel. It explicitly assumes that the axial velocity component is dominant, compared to components in the transverse direction. Thus, some simplified model can be applied to the transverse momentum equations. A typical triangular subchannel arrangement, a control volume for axial momentum equation and control volumes for axial and transverse momentum equations are depicted in Fig. 1.

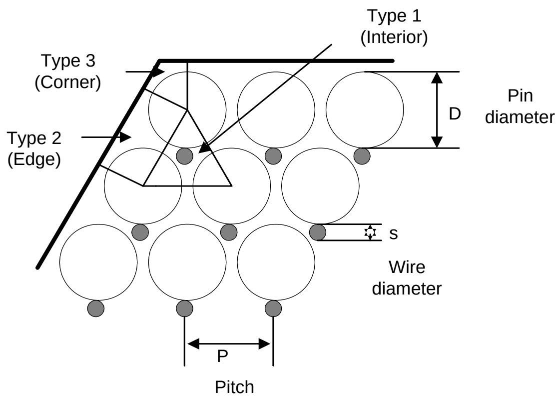

Fig. 1. Schematic diagram of subchannel modeling

Figure 2 shows a steady-state temperature distribution in a core fuel subassembly of the 600MWe demonstration plant being developed at KAERI. The driver subassembly consists of 271 fuel pins within a single wall hexagonal duct. Assuming the same heat generation rate for each fuel pin, a uniform coolant temperature is found around the central region. Since the edge subchannels have a much larger flow area compared to the interior subchannels, the coolant velocity in the outer region is also larger than that in the central region, resulting in a slight lower temperature.

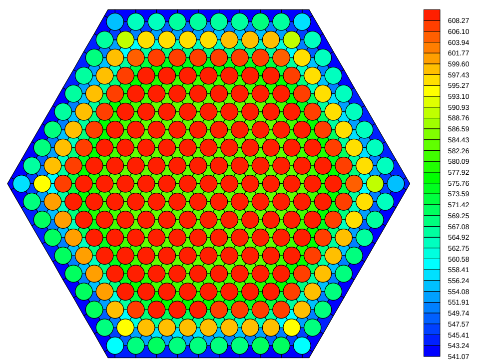
Fig. 2. Coolant and inner-wall temperature distribution in a subchannel of a 600 MWe demonstration plant

2.2 Hot Channel Factors Method

The SFR core thermal-hydraulic analysis generally treats its uncertainty through the hot channel factors method. The hot channel factor, F_{ij}, is an absolute uncertainty ratio to its nominal value. Therefore it is a positive number greater than unity. There are several methods to combine the hot channel factors. In this work, a semistatistical method is employed to analyze the overall uncertainties. Figure 3 displays a schematic diagram to illustrate the semistatistical method, where biased and random uncertainties are separately involved.

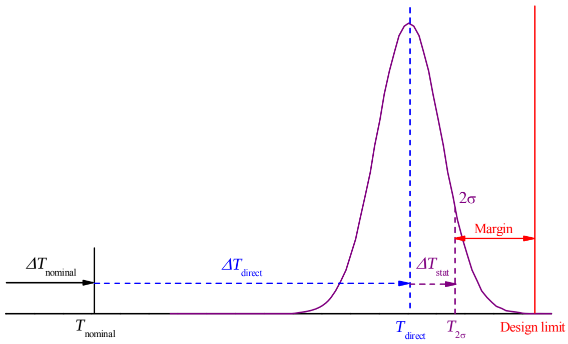

Fig. 3. Schematic illustration of semistatistical analysis

The biased or direct uncertainties assume that all hot channel factors affect the most unfavorable values at the same location and at the same time. The direct uncertainty is calculated as follows:

$$\Delta T_{uncertainty} = \sum_{i=1}^{m} \left\{ \prod_{j=1}^{n} \Delta T_i \cdot F_{ij} \right\}. \quad (1)$$

On the other hand, the random uncertainties are purely statistical. Therefore the propagated overall uncertainty is given by a square root sum of the individual random uncertainties

$$\Delta T_{uncertainty} = \sum_{i=1}^{m} \Delta T_i + 2\left[\sum_{j=1}^{n} \left(\sum_{i=1}^{m} \Delta T_i \cdot (F_{ij} - 1) \right)^2 \right]^{1/2}, \quad (2)$$

where the number 2 is multiplied to address the 2 sigma uncertainty.

2.2 Results and Discussion

The subchannel analysis code MATRA-LMR is combined with the hot channel factors method to estimate the core thermal-hydraulic uncertainties. The calculated results for the maximum cladding temperature are shown in Table I and Fig. 4, comparing to the SLTHEN code. The 2 sigma temperature of the MATRA-LMR code is slightly larger than that of the SLTHEN code. However, their ratios to the nominal values are close to each other. The results demonstrate that the hot channel factors successfully characterize the overall uncertainty combined to the subchannel code.

The subchannel analysis is able to investigate the core thermal-hydraulics including detailed effects of the flow distribution and wire-wrap, compared to the simplified ENERGY model. Moreover, since the MATRA-LMR code has been developed at KAERI during the last years, it can be easily validated and modified to expand its applications.

Table I: 2 sigma temperature calculation results

Temp [^{o}C]	MATRA-LMR		SLTHEN	
	Nominal	2σ	Nominal	2σ
Coolant	558.7	605.7	546.2	590.3
Outer wall	561.6	612.9	550.7	601.7
Middle wall	567.2	618.9	556.0	607.4
*Peak rod and axial position (mm)			55, 1886.7	

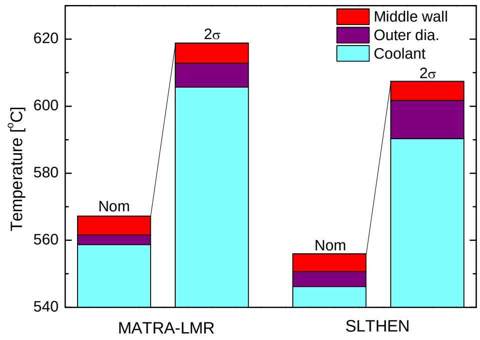

Fig. 4. Comparison of 2 sigma temperature at cladding midwall between two core thermal-hydraulic codes

3. Conclusions

The SFR subchannel analysis combined with the hot channel factors is applied to evaluate the core thermal-hydraulic uncertainties. The results are similar to those of the ENERGY analysis code SLTHEN. As the MATRA-LMR code with the hot channel factors has been already developed, the uncertainty analysis can be applicable to more detailed hydrodynamic phenomena such as inter-subchannel flows and wire-wrap effects.

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