Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Evaluation of 37-Pin Subchannel Flow Mixing Tests for the SLTHEN Code Validation

Sun Rock Choi*, Hyungmo Kim, Seok-Kyu Chang, Hae Seob Choi,
Dong-Jin Euh, Hyeong-Yeon Lee, Jae-Yong Lim
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon 305-503, Republic of Korea
**Corresponding author: choisr@kaeri.re.kr*

1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has performed a reactor design with the final goal of constructing the PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor. The main objective of the PGSFR is to verify TRU metal fuel performance, reactor operation, and transmutation ability of high-level wastes.

The core thermal-hydraulic design is used to ensure the safe fuel performance during the whole plant operation. The fuel design limit is highly dependent on both the maximum cladding temperature and the uncertainties of the design parameters. Therefore, an accurate temperature calculation in each subassembly is highly important to assure a safe and reliable operation of the reactor systems.

The current core thermal-hydraulic design is mainly performed using the SLTHEN (Steady-State LMR Thermal-Hydraulic Analysis Code Based on ENERGY Model) code, which calculates the temperature distribution based on the ENERGY model[1]. This model utilizes simplified correlations experimentally determined for subchannel flow mixing tests. Therefore, the KAERI has carried out validation tests from the PGSFR geometrical and hydraulic specifications[2]. In this work, the 37-pin subchannel flow mixing tests are evaluated by the SLTHEN code.

2. SLTHEN Code

The SLTHEN code employs two region approximations, which enable the momentum equations to be decoupled from the energy equations. In the central region, the mean flow oscillates around each rod as it progresses along the axial direction. In the outer region near the wall, the flow pattern is quite different. This difference in the outer and inner regions of the assembly suggests that the subassembly flow can be divided into two regions.

The resulting energy transport equations for the two regions are then calculated by

$$\rho C_p U_{zI}\frac{\partial T}{\partial z} = (\rho C_p \varepsilon_I + \zeta k)\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+Q \quad (1)$$

$$\rho C_p U_s \frac{\partial T}{\partial s} + \rho C_p U_{zII}\frac{\partial T}{\partial z} = (\rho C_p \varepsilon_n + \zeta k)\frac{\partial^2 T}{\partial n^2} + (\rho C_p \varepsilon_s + \zeta k)\frac{\partial^2 T}{\partial s^2}+Q \quad (2)$$

where the left and right terms represent convective heat transfer and conduction by the enhanced eddy diffusivity, respectively. Q, k and ζ are the volumetric heat source, coolant thermal conductivity and conductivity enhancement ratio from the geometrical factor.

The subchannel flow mixing is characterized by eddy diffusivity (ε) and swirl velocity (U_s) in equation (1) and (2). The eddy diffusivity represents a flow interchange between neighboring subchannels by a wire-induced sweep flow and turbulent mixing. It does not involve a specific flow direction. On the other hand, the swirl velocity is induced in the edge subchannels and follows the direction in which wires are wrapped.

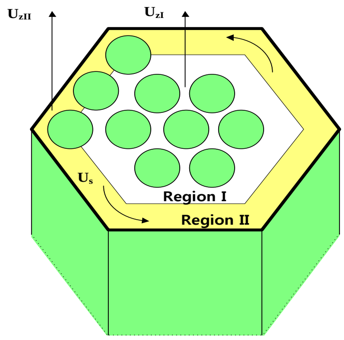


Fig. 1. Two region model in the SLTHEN code

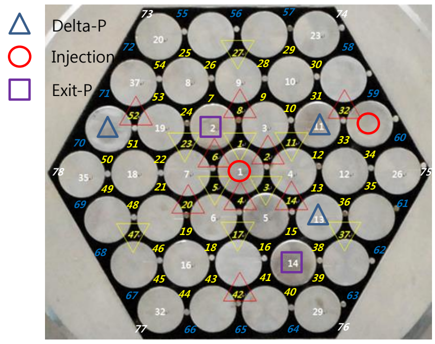


Fig. 2. 37-pin test assembly

3. Subchannel Flow Mixing Tests

A test assembly should reflect the PGSFR thermal-hydraulic conditions. In particular, the pitch-to-diameter ratio (P/D) and height-to-diameter ratio (H/D) of the test assembly should be equal to those of the PGSFR fuel assembly as shown in Fig 2. The number of dummy fuel rods is reduced from 217 to 37 based on the flow rate which can be accommodated in the test facility.

However, the range of Reynolds number in the test assembly should cover the PGSFR design flow range.

The subchannel flow mixing in the test assembly is characterized by injecting electrolyte into a particular subchannel and measuring a concentration distribution at the bundle exit. The electrolyte concentration distribution is measured using a wire-mesh sensing system[2]. To determine eddy diffusivity and swirl velocity ratio, the electrolyte is injected into the center subchannel number 1 and the edge subchannel number 59 in Fig. 2, respectively.

A least square method is used to quantitatively determine flow mixing coefficients from experimental data. Figure 3 displays the difference between SLTHEN calculation and experimental data as a function of eddy diffusivity in a center subchannel injection condition. The eddy diffusivity is determined to be 0.0329 and the comparison with experimental data is shown in Fig. 4. Comparing the experiment and the calculation, a bias error is removed by dividing an average value. The electrolyte distributions at the bundle exit are depicted in Fig. 5.

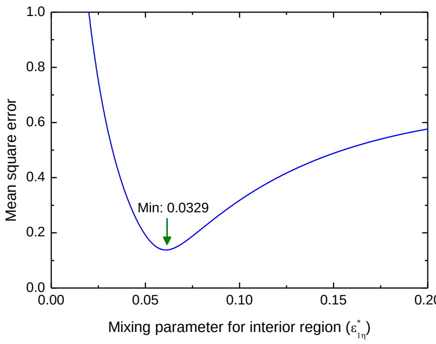


Fig. 3. Least square error as a function of eddy diffusivity

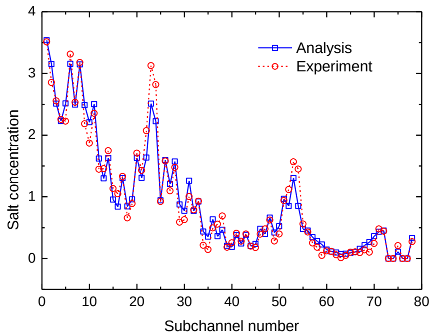
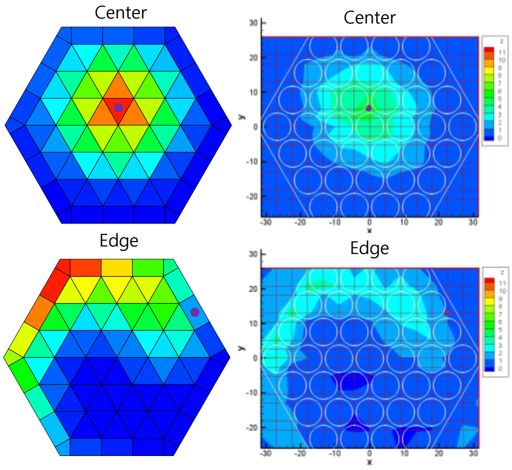


Fig. 4. Comparison between SLTHEN calculation and experimental data

The experimental results are summarized in Table I with the previous correlations of Chiu-Rohsenow-Todreas (CRT) and Cheng-Todreas (CT)[3,4]. The eddy diffusivity is similar to that of the CT correlation. The CRT correlation predicts the eddy diffusivity to be about 30% larger than the experimental value. The swirl velocity is determined with an error of more than 10% with the previous correlations.



(a) SLTHEN (b) Experiment

Fig. 5. Concentration distribution in the SLTHEN calculation and experiment

Table I: Experimental results

	Eddy diffusivity	Swirl velocity ratio
Experiment	0.03285	0.1308
CRT	0.04342	0.1167
CT	0.03317	0.1517

4. Conclusions

The subchannel flow mixing tests are evaluated by the SLTHEN code. The flow mixing coefficients are determined to minimize a difference between the SLTHEN calculation and experimental data. The results show good agreement with the previous correlations.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. NRF-2012M2A8A2025622)

REFERENCES

[1] W. S. Yang, An LMR Core Thermal-Hydraulics Code Based on the ENERGY Model, Journal of the Korean Nuclear Society, Vol. 29, pp. 406-416, 1997.

[2] H. Kim, et al., Investigations of Single-Phase Flow Mixing Characteristics in a Wire-Wrapped 37-Pin Bundle for a Sodium-Cooled Fast Reactor, Annals of Nuclear Energy, Vol. 87, p. 541, 2016.

[3] Chiu C. et al., Turbulent Sweeping Flow Mixing Model for Wire Wrapped LMFBR Assemblies, COO-2245-55TR, Massachusetts Institute of Technology, Cambridge, 1978.

[4] Cheng S. K. and Todreas N. E., Hydrodynamic Models and Correlations for Bare and Wire-wrapped Hexagonal Rod Bundles - Bundle Friction Factors, Subchannel Friction Factors and Mixing Parameters, Nuclear Engineering and Design, Vol. 92, p. 227, 1986.