Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Assessment of the Subchannel Flow Tests with the MIT 37-Pin Hexagonal Assembly for the SLTHEN Code Validation

Sun Rock Choi[*], Jae-Yong Lim
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea
[*]*Corresponding author: choisr@kaeri.re.kr*

1. Introduction

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. The temperature calculation in a fuel assembly requires numerical models and correlations. They should properly reflect geometry and thermal-hydraulic characteristics of the fuel assembly. In particular, since a single-phase heat transfer is only considered in a SFR due to high boiling temperature, most uncertainties on temperature distribution arise from flow models. Thus, experimental validation of assembly flow characteristics is necessary to verify the temperature calculation and to estimate its uncertainty.

A typical fuel assembly in SFRs consists of hundreds of fuel rods arranged in a triangular configuration within a hexagonal duct. Each fuel pin is helically wrapped with a metal wire in the axial direction. Because of the geometrical complexity, a direct CFD (Computational Fluid Dynamics) analysis requires a huge computation capability and is difficult to utilize in the core thermal-hydraulic design which should conduct effective and repetitive calculations. Therefore, there has been a strong need for a simple model to simulate complex flow phenomena in a wire-wrapped fuel assembly.

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]. The model utilizes simplified correlations determined from experiments. This work conducts the code model validation from the subchannel flow tests with the MIT 37-pin hexagonal assembly[2].

2. SLTHEN Code

The SLTHEN code employs two region approximations, which enable the momentum equations to be decoupled from the energy equations. The resulting energy transport equations for the two regions are then calculated by

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

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

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 enhancement ratio from the geometrical factor.

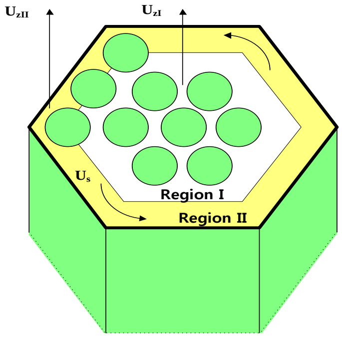

Fig. 1. Two region model in the SLTHEN code

The flow phenomena in a wire-wrapped fuel assembly are divided into the axial flow split and the radial flow mixing at the subchannel level. The axial velocities in each subchannels of a assembly can be obtained from subchannel flow distribution tests. It can calculate the subchannel friction factors from axial velocities and hydraulic diameter of each subchannel, assuming that the pressure drop across each subchannel is same.

The radial flow mixing indicates a mass interchange between neighboring subchannels. In particular, a fuel wire spacer generates a transverse sweeping flow in the wrapped direction. The sweeping flow direction across the interior gap is also change periodically according to axial position. It is represented as the effective eddy diffusivity. On the other hand, the transverse sweeping flow across the edge gap between rod and duct is generated along a specific direction in which a wire is wrapped. This swirl flow in the edge region is modeled as the edge transverse velocity ratio

3. MIT 37-Pin Tests

The MIT test assembly is fabricated to simulate a 37-pin fuel bundle with pitch to diameter ratio (P/D) of

1.154 and lead to diameter ratio (L/D) of 13.4. The geometrical specification is summarized in Table I. Experiments for bundle pressure drop, subchannel flow distribution (flow split) and radial subchannel mixing were performed to evaluate the bundle friction coefficients, flow split factors and flow mixing parameters such as eddy diffusivity and swirl velocity ratio, respectively.

Table I: MIT 37-Pin Geometry

Pin number	37
Pin diameter, mm	15.0
Wire diameter, mm	2.26
Wire lead length, mm	201.5
P/D	1.154
L/D	13.4
Flow area, m2	0.00378
Hydraulic diameter, mm	6.30

The bundle pressure drops were measured at small taps located on the surface of rods. The axial length difference between the taps is directly proportional to the wire lead length to preclude a local flow effect around the pressure taps. The flow distribution measurement for all subchannels including interior, edge and corner subchannels, were performed by using the iso-kinetic method, which corrects a flow disturbance from the instrument itself. The subchannel radial flow mixing was measured using resistance probes installed at the bundle exit. A salt tracer of electrolyte was injected into a particular subchannel and a concentration distribution at the bundle exit was measured using the local probes.

3.1 Bundle Pressure Drop

Measuring the bundle pressure drops, the friction coefficients as a function of Reynolds number is calculated as shown in Fig. 2. The tests were conducted from laminar to fully turbulent regime. The results are compared with the Cheng-Todreas (CT) correlation[3]. A transition region from laminar to turbulent flow was observed between 600 and 10,000 in Reynolds number. The CT model slightly overpredicts the bundle friction coefficients in the turbulent regime.

3.2 Subchannel Flow Distribution

Figure 3 shows a subchannel flow distribution within the MIT 37-pin assembly at Re=10,480. Flow rates were measured for 18 interior and 18 edge subchannels at the iso-kinetic condition. The flow rates in the edge region are much larger than those in the interior region but the values in the same region are similar to each other. The CT correlation show good agreement with experimental values.

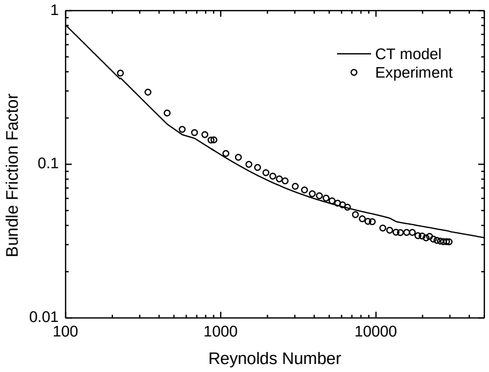

Fig. 2. Bundle friction coefficients versus Reynolds number

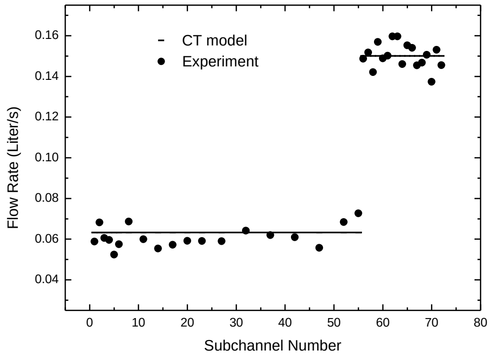

Fig. 3. Subchannel flow rate in the test assembly

The flow split factors as a function of Reynolds number are illustrated in Fig. 4. There is a strong transition of flow split factors during a flow transition region below Re=12,500. This phenomenon is similar with the CT model. However, larger deviations from the model were observed in the experimental values.

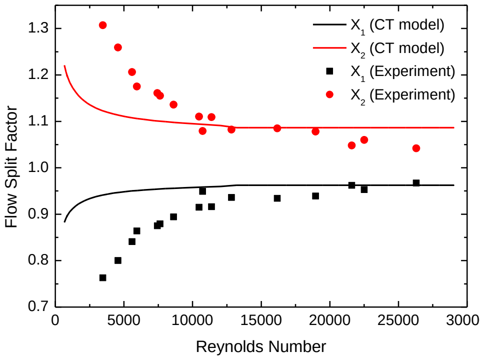

Fig. 4. Flow split factors as a function of Reynolds number

3.3 Radial Subchannel Mixing

To determine eddy diffusivity and swirl velocity ratio, the electrolyte is injected into the center subchannel and the edge subchannel, respectively. A least square method is used to quantitatively determine flow mixing coefficients from experimental data. The SLTHEN code predictions with the determined coefficients are displayed in Fig. 5.

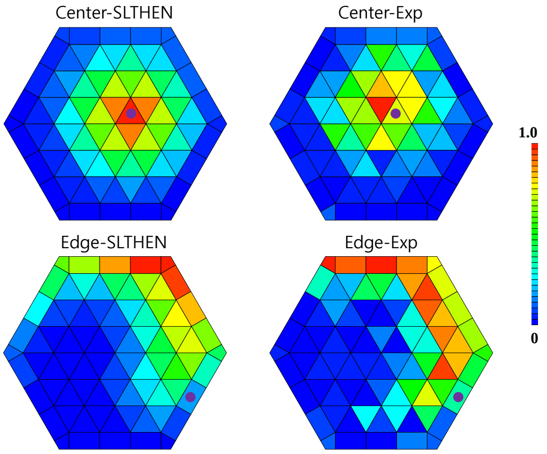

Fig. 5. Concentration distributions in the code predictions and experiments at Re=12,200

The dimensionless eddy diffusivity and transverse velocity ratio as a function of flow rate were determined from the MIT 37-pin data as shown in Fig. 6 and 7, respectively. Similar to the flow split factors, the flow mixing coefficients are nearly constant in turbulent regimes and change abruptly as it approaches the laminar region. The CT model adequately predicts this trend, but show a little random error.

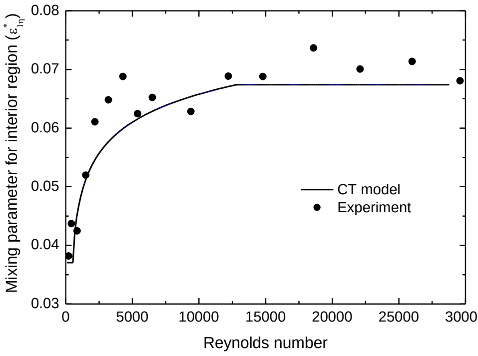

Fig. 6. Dimensionless eddy diffusivity versus Reynolds number

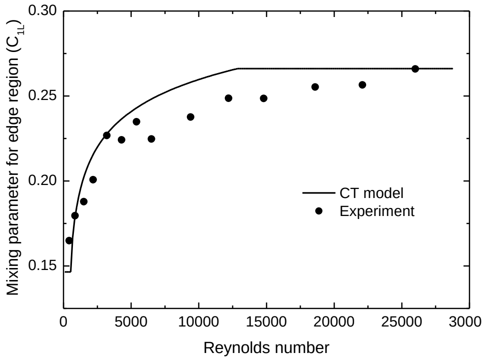

Fig. 7. Dimensionless swirl velocity ratio versus Reynolds number

4. Conclusions

The subchannel flow tests for the MIT 37-pin assembly are evaluated to validate the SLTHEN code. The results are compared with the CT models and generally show good agreement. However, the CT model in the code predicts slightly larger friction coefficients than the experimental values in the turbulent regime. The flow split factors show larger deviation in the transition region. The flow mixing coefficients determined by the SLTHEN code are similar with the correlation.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. NRF-2012M2A8A2025624)

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] Cheng S. K., Constitutive Correlations for Wire-Wrapped Subchannel Analysis under Forced and Mixed Convection Conditions, PH.D. Thesis, MIT, 1984.

[3] 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.