Validation of the MATRA-LMR-FB Code for Two Typical Flow Paths with Blockage

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1. Introduction

The high heat capacity and the large heat transfer coefficient are the excellent characteristics of a liquid metal as a coolant. This advantage of a liquid metal enables the compact core design in a liquid metal-cooled reactor (LMR) with higher heat flux than other type of nuclear reactors. However, when an obstacle is formed in the flow path, the local temperature of the coolant increases at the downstream of the blockage and the integrity of the fuel clad can be threatened.

In the design of a LMR, the consequence of the blockage formation in a fuel assembly is deliberately analyzed with a subchannel analysis code to show the core coolability is maintained without exceeding the temperature limits. If a blockage occurs, the axial flow rate decreases drastically up to a certain distance downstream from the blockage and a re-circulating wake is formed. Therefore, the analysis code for the flow blockage requires a proper numerical scheme and thermal-hydraulic model to treat the re-circulating flow.

For the analysis of a blockage accident, the KAERI has developed the MATRA-LMR-FB code [1] by enhancing the MATRA-LMR code [2]. The MATRA-LMR-FB code uses the distributed resistance model [3] to describe the sweeping flow formed by the wire-wrap and to model the re-circulation flow after a blockage. The hybrid difference scheme and the state-of-the-art turbulent mixing models are also adopted to describe the convective terms in a low velocity re-circulating wake region and to describe the inter-channel mixing correctly. In this study, the accuracy of the code is validated for the experiments performed in two typical types of fuel assembly, the wire-wrapped and the grid-spaced.

2. Analysis

For the validation of the MATRA-LMR-FB code, the THORS test [4] performed at ORNL and the KNS 169-pin test [5] by KfK Karlsruhe have been analyzed.

2.1 ORNL THORS Test

The selected THORS tests are for the FFA-2A [4] and FFM-5B test sections, which simulate the normal flow path and the blocked, respectively. In these tests, the fuels are wire-wrapped. The fuel rods whose diameter is 5.842 mm are arranged in a triangular pitch within a hexagonal duct. The diameter of the wire wrap around the internal rods is 1.4224 mm and its diameter around the peripheral rods near the hexagonal duct is 0.7112 mm. In the unblocked tests, the power distributions were uniform.

On the contrary, in the blocked tests of FFM-5B, the rod power varied radially. The sodium flow enters from the bottom and passes the entrance region of about 406.4 mm, then the heated section, finally the exit region. The length of the heated section is 457.2 mm and the exit region is about 152.4 mm in the test. The thermocouples are located at the middle of the exit region. A plate type of blockage is positioned at 101.6 mm from the start of the heated section. About one third of the flow area is blocked at the edge around the corner subchannels as shown in Figure 1. Two cases of normal flow condition and two cases of blocked flow condition are analyzed. Table 1 summarizes the experimental condition of the ORNL test.

Table 1. Boundary conditions for the ORNL THORS tests

Flow condition	Normal Path		Blocked Path	
Run No.	1143	1459	101	109
Velocity (m/s)	7.16	0.10	6.93	0.48
Inlet temp.(^{o}C)	315	315	323.6	268.4
Heat flux (W/cm^2)	173.5	2.68	90.95	33.12
Power distribution	Uniform	Uniform	0.975-1.036	0.957-1.109

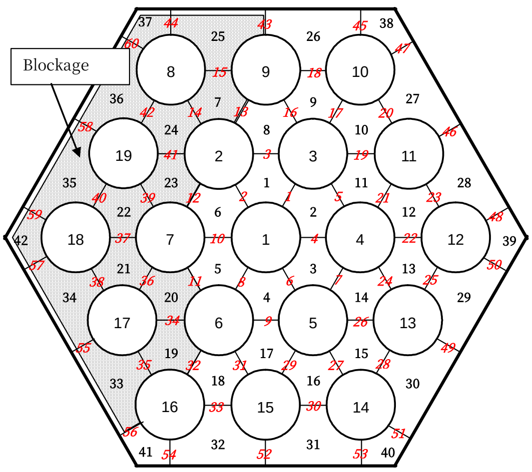

Figure 1. Configuration of blockage in THORS test

2.2 KNS 169-pin Test

The KNS-169-pin test [5] was performed at KfK Karlsruhe with the hexagonal flow path. The test run numbers 1 and 6 are evaluated, in which sodium was a working fluid and 49 % of the central part of the flow path was blocked. The simulated subassembly was the 169-pin bundle of the SNR 300 geometry and 88 rods located in the blocked region were heated.

The test section length is modeled to be 1,016 mm and the 7 spacer grids are assumed to be located at every 150 mm. The axial length of the flow path is divided into 74 nodes. The blockage is formed at the center of the third grid from the bottom. The 15 mm-thick grid containing the blockage is divided into two axial nodes and the 3 mm-thick blockage is assigned to be located at the lower grid node. The inlet temperature and flow velocity are given as boundary conditions, which are summarized in Table 2.

2.3 Results

The prediction results of MATRA-LMR-FB for the two typical flow paths are summarized in Figures 3 and 4. It is noted that the code predicts the exit temperatures quite accurately for the wire-wrapped channels. This is mainly because of the distributed resistance model, which describes the momentum change due to the wire-wrap accurately. The predicted mean and standard deviation of the non-dimensionalized temperatures for the wire-wrapped flow path are 1.013 and 0.047, respectively.

The predictions for the test with spacer grid show some deviations from the measured temperature distribution. The mean and standard deviation for the grid-spacer test are 1.007 and 0.316, respectively. It is analyzed that the MATRA-LMR-FB under-predicts the re-circulation flow at the center of the blockage, which may come from an inaccuracy in the mixing characteristics and/or from the numerical diffusion when there exists a spacer grid.

3. Conclusion

Based on the analysis results for the temperature data, the accuracy of the MATRA-LMR-FB code is evaluated quantitatively. The code predicts very accurately the exit temperatures measured in the subassembly with wire-wrap. However, the predicted temperatures for the experiment with spacer grid show some deviations from the measured. To enhance the accuracy of the MATRA-LMR-FB for the flow path with grid spacers, it is suggested to improve the models for pressure loss due to spacer grid and the modeling method for blockage itself. The developed MATRA-LMR-FB code is evaluated to be applied to the flow blockage analysis of KALIMER-600 which adopts the wire-wrapped subassemblies.

Table 2. Boundary conditions for the KNS-169 tests

Run No.	1	6
Flow velocity (m/s)	4	1
Inlet temperature (^oC)	404	404
Heat flux (W/cm^2)	67.7	17.9
Temp. gradient (K/m)	113	117

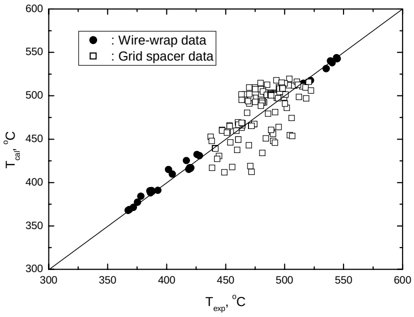

Figure 3. Temperature prediction with MATRA-LMR-FB

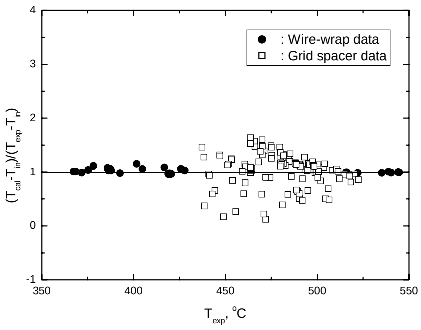

Figure 4. Prediction of non-dimensionalized temperature

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