Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Validation of a Steam Generator Heat Transfer Model for the TASS/SMR Code

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1. Introduction

To identify the safety margin for the safety related design basis event of a 65-MWt advanced integral reactor and to evaluate its design performance, the Transients And Setpoint Simulation/System integrated Modular Reactor (TASS/SMR) code has been developed [1]. Till now, the verification and validation of the TASS/SMR code has only been established by using simplified and analytical problems or a reliable system code. Recently, several kinds of experiments have been performed to support the validation of the TASS/SMR code by focusing on an identification of the heat transfer characteristics for the major components and the system characteristics of a passive residual heat removal system.

In this paper, the validation works of the TASS/SMR code by using the experimental data related to a heat transfer for a helically coiled steam generator (SG) are described.

2. TASS/SMR Steam Generator Heat Transfer Model

In the 65-MWt advanced integral reactor, twelve identical SG cassettes are located in the annulus part between the reactor vessel and the core support barrel. Contrary to the SG of commercial reactors, the SG of the advanced integral reactor is a helically coiled once-through type. The primary coolant flows downward in the shell side of the SG, while the secondary feed-water flows upward in the tube side. During a normal operation, the feed-water is evaporated in the tube inside and it exits the SG cassettes nozzle header with a superheated steam condition at 3.5 MPa of about 40 K. In the tube side of the SG cassettes, three different kinds of phases, i.e. subcooled water, saturated condition and superheated steam, exist.

For the calculation of a heat transfer at the SG cassettes of the advanced integral reactor, various kinds of correlations have been incorporated in the TASS/SMR code [1]. Firstly, a single-phase heat transfer coefficient at the shell side of the SG is obtained by using the Zukauskas equation. On the other hand, the Mori-Nakayama correlation, the modified Chen correlation and the Churchill-Chu correlation have been used to calculate a single-phase forced convective heat transfer coefficient, a nucleate boiling heat transfer coefficient and a single-phase natural convective heat transfer coefficient at the tube side of the SG.

3. Validation of the SG Heat Transfer Model

The validation of the SG heat transfer model has been accomplished by using the experimental data of a prototype of the SG cassette of the advanced integral reactor [2]. The SG cassette is made of 96 coiled heat exchanger tubes, which have a 7 mm inner diameter and a 1.5 mm thickness. Also, it has an active height for a heat transfer of 1150 mm and a heat transfer area of 26.2 m^2. Instead of using twelve SG cassettes, one SG cassette was used during the experiment. Therefore, at a 100% power nominal condition, the mass flow rates of the primary and the secondary sides of the SG cassette were reduced to 28.29 kg/s and 2.0 kg/s, which are 1/12 of the mass flow rates of the primary and the secondary sides of the advanced integral reactor, respectively. The experimental matrix for the identification of the performance of the SG cassette is shown in Table 1.

A nodalization consisting of 27 volumes and 25 paths has been used for the validation. In the nodalization, the inlet and the exit positions of the primary coolant flow and the feed-water flow are modeled as flow boundaries and pressure boundaries, respectively. The inlet enthalpies of the primary and the secondary sides are calculated by considering the system pressure and the coolant temperature at the inlet positions of the SG cassette.

The pressures at the inlet position of the primary side of the SG cassette are shown in Fig. 1. On the condition that the mass flow rate of the primary side is a high condition (experimental index = 1, 2, 3, 4, 5, 18, 20, 21 and 22), the calculated system pressures are similar to the experimental data: however, the calculated system pressures are somewhat lower than the experimental data in the case of a lower mass flow rate of the primary side. On the other hand, the pressures at the inlet position of the secondary side of the SG cassette are predicted well by the TASS/SMR code, as shown in Fig. 1.

The fluid temperatures at the exit positions of the primary and the secondary sides of the SG cassette are shown in Fig. 2. The calculated fluid temperatures at the exit position of the primary side are similar to the experimental data although the thermal hydraulic conditions of the experiments are considerably different. However, even though the steam temperatures calculated by the TASS/SMR code behave similarly to the experimental data, the calculated steam temperatures at the exit position of the secondary side are higher than those of the experimental data. This is induced by a heat removal to the atmosphere, which reduces the steam temperatures at the exit position of the secondary side. In the calculation using the TASS/SMR code, a heat transfer to the atmosphere is not considered and, as a result, this causes higher steam temperatures at the exit position of the secondary side, when compared to those of the experimental data.

The heat transfer rates through the SG cassette are shown in Fig. 3. The heat transfer rates for the experiment are calculated by using the mass flow rates and the enthalpy differences between the inlet and exit positions of the secondary side of the SG cassette. According to the figure, the calculated heat transfer rates through the SG cassette are similar to those of the experimental data for all the considered experimental conditions.

4. Conclusion

The SG heat transfer model of the TASS/SMR code has been validated by using experimental data with a prototype of the SG cassette of a 65-MWt advanced integral reactor. According to the analysis results, the major thermal hydraulic parameters, including the pressures at the inlet positions of the primary and the secondary sides, the fluid temperatures at the exit position of the primary side, and the heat transfer rates through the SG cassette, are predicted well by the TASS/SMR code. However, the steam temperatures at the exit position of the secondary side of the SG cassette, calculated by the TASS/SMR code, were generally higher than the experimental data. These higher steam temperatures may be caused by the ignorance of a heat removal to the atmosphere, which reduces the steam temperatures at the exit position of the secondary side.

REFERENCES

[1] Hwang et al., "Model description of TASS/SMR code," KAERI/TR-3082/2005, 2005.
[2] KAERI, "Steam generator mode: Report on thermal hydraulic test results," KAERI internal report, 2005.

Table 1. Experiment matrix

Experiment index	Primary side			Secondary side		
	T_{in}	P_{in}	Flow	T_{in}	P_{in}	Flow
1	583.2	15.0	29.0	423.2	3.45	0.02
2	583.2	15.0	29.0	423.2	3.45	0.04
3	583.2	15.0	29.0	423.2	3.45	0.06
4	583.2	15.0	29.0	423.2	3.45	0.08
5	583.2	15.0	29.0	423.2	3.45	0.1
6	574.2	15.0	14.5	323.2	1.6	0.2
7	574.2	15.0	14.5	323.2	1.6	0.2
8	574.2	15.0	10.44	323.2	1.6	0.2
9	574.2	15.0	7.25	323.2	1.6	0.2
10	583.2	15.0	4.4	323.2	3.45	0.36
11	575.2	15.0	10.44	323.2	1.6	0.4
12	575.2	15.0	7.25	323.2	1.6	0.4
13	583.2	15.0	4.4	323.2	3.45	0.4
14	583.2	15.0	4.4	323.2	3.65	0.4
15	583.2	15.0	4.4	323.2	3.25	0.4
16	586.2	15.0	4.4	323.2	3.45	0.4
17	580.2	15.0	4.4	323.2	3.45	0.4
18	575.2	15.0	29.0	323.2	3.45	0.4
19	583.2	15.0	4.4	323.2	3.45	0.44
20	576.2	15.0	29.0	323.2	3.45	0.6
21	577.2	15.0	29.0	323.2	3.45	0.8
22	578.2	15.0	29.0	323.2	3.45	1.0
23	583.2	15.0	14.5	323.2	3.45	1.0
24	583.2	15.0	7.25	323.2	3.45	1.0

T_{in}: K, P_{in}: MPa, Flow: kg/s

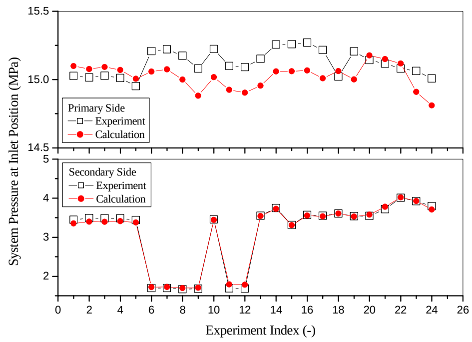

Fig. 1 The system pressures at the inlet positions

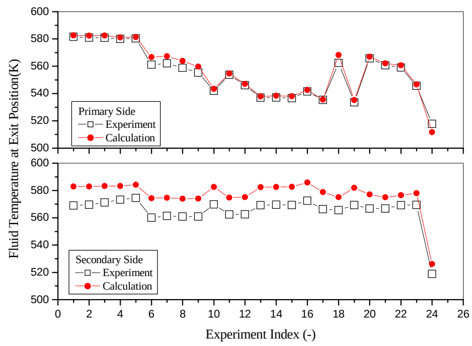

Fig. 2 The fluid temperatures at the exit positions

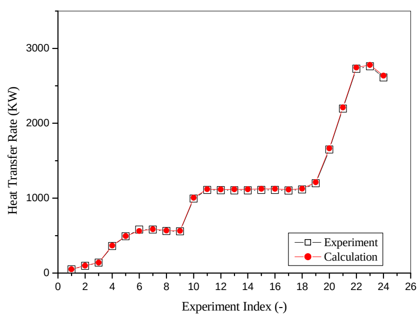

Fig. 3 The heat transfer rates through SG cassette