Thermal Hydraulic Characteristics of the Steam Generators at the ATLAS Facility

Yeon-Sik Kim, Nam-Hyun Choi, Bok-Deuk Kim, Kyeong-Ho Min, Sung-Jae Lee, and Ki-Yong Choi
Korea Atomic Energy Research Institute, Thermal Hydraulics Safety Research Division,
P.O.Box 105, Yuseong, Daejeon, 305-600, Republic of Korea
Corresponding author: yskim3@kaeri.re.kr

1. Introduction

A thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation), was constructed at the Korea Atomic Energy Research Institute (KAERI) in 2006. It is a 1/2 reduced height and 1/288 volume scaled test facility based on the design features of the APR1400, an evolutionary pressurized water reactor developed by the Korean nuclear industry[1]. Preliminary tests were being carried out in order to characterize the basic thermal hydraulic characteristics such as pressure drop distribution, temperature distribution along the primary loop, and natural circulation characteristics[2,3].

Since 2007, many tests have been carried out to simulate the APR1400 design bases accidents, e.g. LBLOCA reflood phase, DVI line or cold leg break SBLOCA, and SGTR. For each test, major systems, e.g. reactor coolant system and secondary system, should be on the initial steady state condition. To achieve a steady-state condition, the heat balance between the primary and secondary systems must be maintained. In the reference design of the APR1400 steam generator, an economizer concept is included to increase the thermal efficiency of the steam generator. In addition to the economizer, the ATLAS steam generator adopted two separate pipes for cold-side and hot-side downcomers to simulate the reference steam generator. This paper is focused on the findings of the thermal hydraulic characteristics of the steam generator in the ATLAS facility

2. Summary of the ATLAS Steam Generator

The steam generator(SG) is an important component that delivers the primary heat to the secondary system. A summary data of the ATLAS steam generator is given in Table 1[4]. There is a tube bundle in the shell side, which provides a pressure boundary between the reactor coolant system and the secondary system. The design condition of the tube bundle follows that of the primary system. Figure 1 shows the schematic design of the steam generator. As shown in Fig.1, there are two external pipes to simulate the cold- and hot-side annulus downcomers of the reference plant, e.g. longer one for hot-side, shorter one, cold-side. Actually, a divider plate is equipped at the center and lower region of the tube bundle as in the reference steam generator, which provides an economizer region on the cold side. As depicted in Fig.1, the ATLAS steam generator is a typical recirculation type with external downcomers.

Table 1 Summary data of the ATLAS steam generator

- Desgin P[MPa]/T[°C]	10/310
- No. of SGs	2
- No. of U-tubes per SG	176
- Tube Material	SA213-TP347
- U-tube ID/OD [mm]	12.0/14.2
- Average tube length [m]	8.818
- H/T area per SG [m^2]	63.87(51.18/12.7)
- Downcomer type	External Pipe

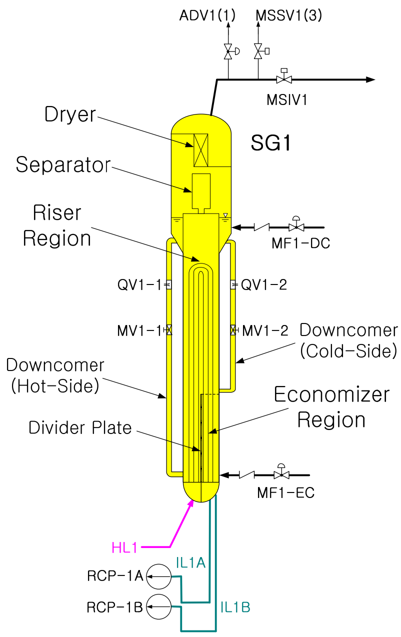

Fig. 1 Schematics of the ATLAS steam generator

3. Thermal Hydraulic Characteristics of the Steam Generator

For the flow characteristics of the steam generator shell-side had been reported in the previous paper[5]. From then, ATLAS team had investigated the flow characteristics of the SG shell-side till the end of 2008. From the investigation, the ATLAS team determined to change the downcomer flowmeter from a turbine to a bidirectional type, which was developed by the ATLAS team itself, for increasing the reliability of the downcomer flowrate measurement. As a result, the downcomer flowrate shows more stable trend than the previous results[5].

Before starting a specific test, a quasi-steady state condition was confirmed by checking the operational parameters, e.g. pressures and temperatures, achieved in the primary and secondary systems. To confirm the operational characteristics of the steam generator during the quasi-steady state, the secondary parameters, e.g. feed flow rate and recirculation ratio etc., should be evaluated for the quasi-steady state. Figs. 2 and 3 show the trends of the secondary-side parameters during the steady-state condition for the DVI-09 test. In this case, the core power was about 1.6MW and the steam generator pressure is 7.83MPa, respectively. The water level of each steam generator was about 50% in a narrow range(SP: 4.17m). As shown in these figures, the downcomer flowrates have constant values for the hot side downmers(QV-SGDC1,2-01), but some stably oscillatory patterns for the cold side downcomers(QV-SGDC1,2-02). It can be interpreted because of the driving force for the flow. The driving force for the downcomer flow is given by the hydraulic head between the water level and the bottom nozzles. A larger one is found in the hot-side downcomer, so nearly constant flowrates are shown in those sides.

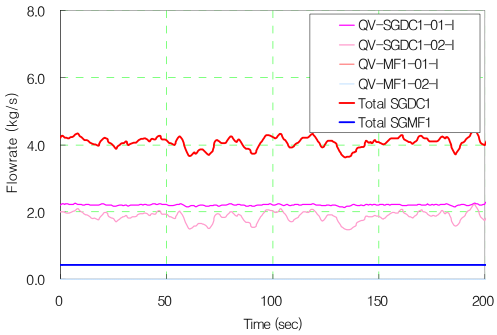

Fig.2 Secondary flowrates in steam generator 1

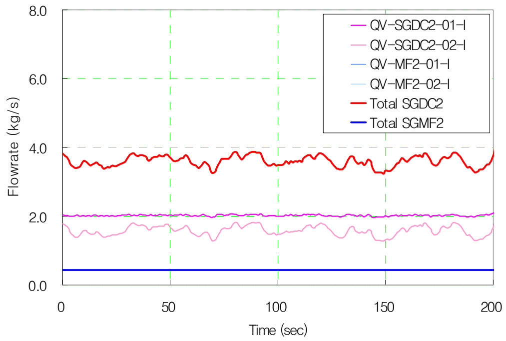

Fig.3 Secondary flowrates in steam generator 2

Using the main feedwater and the downcomer flowrates, the circulation ratio can be calculated as shown in Fig. 4. There are two nozzles for the main feedwater injection, e.g. one for the downcomer and the other for the economizer. For a higher power level, most of the main feedwater is supplied through the economizer nozzle as shown in Figs. 2 and 3.

The circulation ratio for a quasi-steady state under a given condition, as described before, ranges from around 9 to around 11, which is a quite reasonable value with respect to the real plant. In the reference design, the circulation ratio ranges from around 3 to around 30 depending on the power level. The oscillatory patterns of the circulation ratio are due to those of the downcomer flowrates as explained before.

As can be found in the figure 4, the oscillation patterns of the circulation ratios, which are mainly due to cold side downcomer flowrates, are quite similar to those of the water levels. From this, it can be said that the oscillatory flow patterns of the cold side downcomers are strongly dependent upon those of water levels.

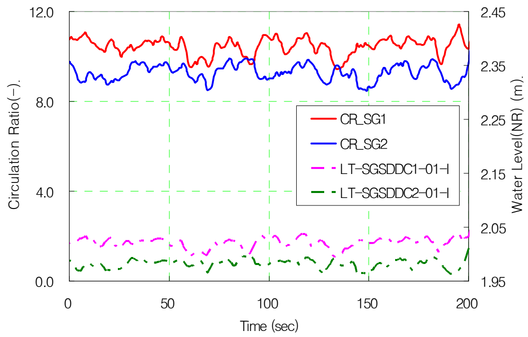

Fig.4 Circulation ratios of the steam generator 1&2

4. Conclusion

In the ATLAS steam generators, all the flowrates of the downcomers show quite good trends with stably oscillatory patterns of the cold side downcomers. Nearly constant flow patterns are found in the hot-side downcomers, which are the reason for the larger hydraulic head in those sides. The circulation ratio for a quasi-steady state under a given condition from around 9 to around 11.

Acknowledgement

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