Experimental Verification for the Long-term SWR model of the SELPSTA code

Jae-Hyuk Eoh, Ji-Young Jeong, Seong-O Kim

Fluid Engineering Division, Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-Gu, Taejon, Korea, 305-353
jheoh@kaeri.re.kr ; jyjeong@kaeri.re.kr ; sokim@kaeri.re.kr

1. Introduction

The sodium-water reaction (SWR) event occurring in a steam generator (SG) of a liquid metal reactor (LMR) is one of the key issues for the system design. In the long-term period of the SWR phenomena, an initial wave propagation effect is subsided and the system responses depend only on the characteristics of the bulk motion with the quasi-steady pressurization of the system due to a continuous chemical reaction. From previous studies [1], a long-term SWR model reflecting the mass and energy transfer effect was developed and the SELPSTA [2] code was also formulated. This work describes the experiment for the verification of the long-term SWR analysis model, and it also provides the model verification results to investigate the feasibility of the physical model and the numerical method implemented in the SELPSTA code.

2. Description of work

2.1 LMET model

In an actual LMR design, since the intermediate heat transport system (IHTS) is a closed loop before the rupture disk break, the long-term SWR phenomena can be regarded as the pressure and temperature transients of the cover gas space because it accommodates the entire thermal-hydraulic responses of the system. For this reason, a physical model for a long-term mass and energy transfer (LMET) was developed by using these peculiar features. From the former study [1], the physical assumptions implemented in the LMET model are feasible and practicable for a long-term SWR analysis from the view point of a conservative manner.

2.2 Experiment

Since the long-term system responses during the SWR depend only on the characteristics of the bulk motion, to save on the cost and effort of an actual sodium experiment, a 1/10 scale-down SWR mock-up test [3] was performed for an experimental verification of the LMET model. Actually, the dominant operating fluids affecting the SWR long-term phenomena are the sodium and hydrogen gas, but the mock-up test uses sub-cooled water to describe the actual sodium flow in the shell-side SG, and it also uses a high pressure air injection to simulate the hydrogen generation. In this case, proper analogies reflecting the flow and heat transfer effects were sufficiently considered. Also, to minimize the uncertainty of the analogies for the mock-up test, the relations between the sodium-hydrogen and water-air were carefully investigated and they were applied to obtain the test conditions.

The entire mock-up test loop including the test vessel and pipings are filled with sub-cooled water, and the high pressure air is injected into the test vessel to describe the hydrogen generation caused by the reaction. The flow obstacles are situated in the center of the test vessel to properly simulate the helically coiled heat transfer tubes in the shell-side sodium flow path. The water is circulated across the flow obstacles to simulate the actual tube bundles affecting the injected air bubble movement towards the cover gas space. There are three air injection nozzles to describe the actual tube leak positions, which are located on the top, middle, and the bottom part of the tube bundle region. The mock-up test facility and the plane and vertical views for the flow obstacles are shown in Fig. 1. The test was performed for a total of 9 cases with respect to the cases of the three air injection nozzle positions and the three fluid flow conditions.

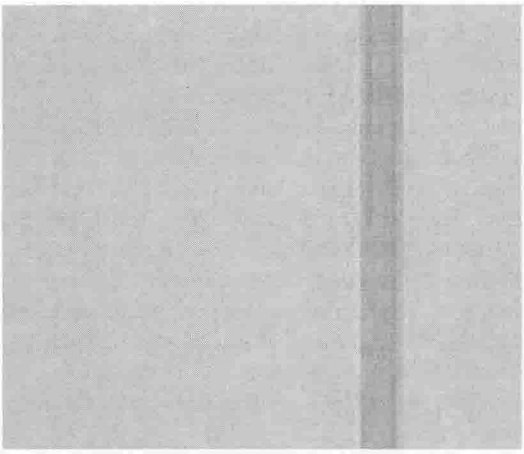

Figure 1. SWR mock-up test facility and flow obstacles

All the cases of the test were carried out three times to certify each test condition and to reduce the uncertainties generated in each test procedure. The experimental conditions are summarized in Table 1.

Table 1. Experimental conditions

Cover gas	Argon
Pressure	0.1 *MPa* (initial)
Temperature	13-14 °*C* (initial)
Circulating	Sub-cooled water
Fluid	12-13 °*C* (initial)
Temperature	Stagnant, 6.5*l/sec*,
Flow rate	10.5*l/sec*
Injection gas	Compressed air
Temperature	90 °*C* (fixed)
Flow rate	< 30 *cc/sec*
Pressure	0.2 *MPa*
Position in	Top / Middle / Bottom
bundle	Install / Remove
Flow obstacles	

2.3 Model verification with test results

Fig. 2 shows a comparison of the measured and numerical results regarding the pressure transients of the cover gas.

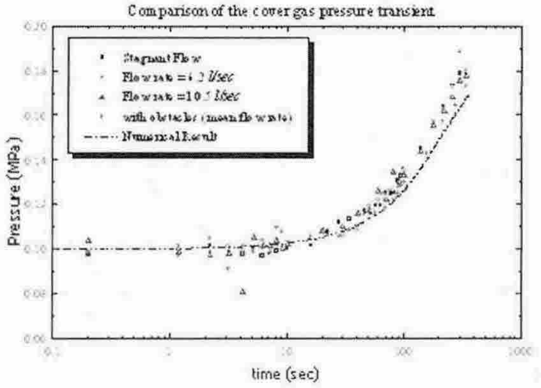

Figure 2. Comparison of the cover gas pressure variation

In the figure, the hollow symbols of the square, circle and the upper triangle mean the test results of the stagnant and the two dynamic flow conditions, such as the flow rate of 6.2 *l/sec* and 10.5 *l/sec*, respectively. Also the solid circular symbol means the measured data with the flow obstacles under the mean circulating flow conditions defined as the average of the two dynamic flow rates. The numerical result for the pressure variation agrees well with the experiment. Even though some measured data have relatively large deviations from the numerical prediction, most of them are distributed well to within 5% of mean values. Fig. 3 shows a comparison of the experimental and numerical results regarding the temperature variance of the cover gas, and the numerical result agrees with the measured data for the first 90 seconds of the experiment. However, since the measured temperature increments of the entire flow conditions decline as time goes on, the numerical results over predict the temperature transient at the end of the test. The difference between the SELPSTA calculation and the measured data is caused by the following reasons. In view of the energy transfer between the injected air and the sub-cooled water, the hot air is easily deprived of its energy by the cold water because the heat capacity of the sub-cooled water is much larger than that of the air. Accordingly, as time passes, the heat transfer rate from the hot air to the cover gas is gradually reduced due to the energy loss, and thus the temperature increments of the cover gas dwindle.

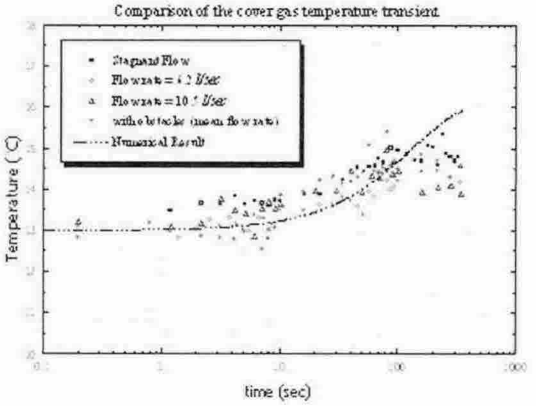

Figure 3. Comparison of the cover gas temperature variation

From the thermal-hydraulic foundation for the diminution of the temperature increment, it was also inferred that the heat loss to the environment through the test vessel is another reason for the phenomena.

3. Conclusions

For the verification of the LMET model, a 1/10 scale-down mock-up test was performed with sufficient considerations of the quasi-steady features of the SWR event, and it was found that the LMET model can replicate the overall phenomena of the experiment with a physically reasonable understanding. Even though the pressure transient of the system is coupled with its temperature variation, it was also found that the long-term SWR analysis model implemented in the SELPSTA code is useful for simulating the quasi-steady SWR phenomena.

ACKNOWLEDGEMENT

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