Multi-target Wastage Phenomena on Steam Generator Tubes During an SWR Event

Ji-Young Jeong, Jong-Man Kim, Tae-Joon Kim, Jae-Hyuk Eoh, Jong-Hyeun Choi, Yong-Bum Lee
Korea Atomic Energy Research Institute
Daeduk-daero 1045, Yuseong-Gu, Daejeon, Korea, 305-353
jyjeong@kaeri.re.k; kimjm@kaeri.re.kr; tjkim@kaeri.re.kr; jheoh@kaeri.re.kr; jhchoi2@kaeri.re.kr; yblee@kaeri.re.kr

1. Introduction

The Korean sodium cooled fast reactor, KALIMER-600 (Korea Advanced LIquid MEtal Reactor) of which the electric output is 600MWe, was developed. The steam generator (SG) of this system is a shell-and-tube type counter-current flow heat exchanger, which is vertically oriented with fixed tube-sheets. A direct heat exchange occurs between the shell-side sodium and the tube-side water at the SG unit [1]. Feed-water enters the inlet nozzle at the lower part of the unit and it flows upward along the helically coiled heat transfer tubes. The inflow sodium is cooled down at the bundle region and then flows out through the sodium outlet nozzle at the bottom of the unit. The typical configuration of the KALIMER-600 SG is shown in Figure 1.

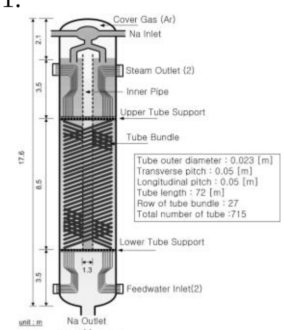

Figure 1 Schematic of KALIMER-600 Steam Generator

In a steam generator, sodium and water are separated by the heat transfer tube wall and it makes a strong pressure boundary between the shell-side sodium and the tube-side water/steam. For this reason, if there is a small hole or crack, even with a pin hole, on heat transfer tubes, a large amount of water/steam would leak into the liquid sodium due to the high pressure difference more than 150 bars [1], and an exothermic sodium-water chemical reaction takes place as a result. This type of sodium-water reaction (SWR) has been considered as one of the most important safety issues to be resolved.

From previous studies [2][3], it was obviously figured out that the number of ruptured tubes during an SWR event is one of the most significant factors to determine the temperature and pressure transient. Any subsequent tube rupture behavior in the vicinity of the initially postulated single ruptured tube should be evaluated by considering the single- and multi-target wastage phenomena.

Wastage is defined as damage to the structural material (e.g. heat transfer tubes) due to an impingement of the highly corrosive reaction product. Since the impingement may cause wastage of the neighboring heat transfer tubes, a subsequent tube failure can occur in a very short time [4-5]. This is called “multi-target wastage”.

Therefore, it is very important to predict these phenomena quantitatively from the view point of designing a steam generator and its leak detection systems.

In this study, to investigate the additional tube rupture behavior near the failed tube, multi-target wastage tests were carried out for the simulated target assembly made with a modified 9Cr-1Mo steel tube bundle.

2. Experimental

2.1 Experimental apparatus

The tube bundle wastage tests were conducted at KAERI by using a second version of the sodium-water reaction test facility. The schematic diagram of this facility is shown in Figure 2.

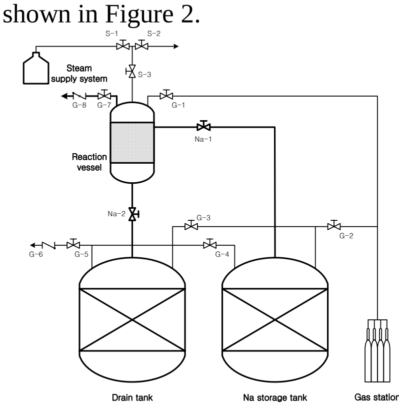

Figure 2 Experimental apparatus

The facility consists of a reaction vessel, a sodium storage tank, and a sodium dump tank and a steam supply system. The reaction vessel is a 50-cm-diameter by 100-cm-long stainless steel vessel. Steam was supplied into the reaction vessel at a pressure of 150kg/cm^2, which was achieved by using a gas booster. The tube bundle assembly with 5×5 layer was made of a modified 9Cr-1Mo steel pipe. Figure 3 shows the reaction vessel installed with the tube bundle assembly.

3.2 Experimental conditions

Circular type defects were simulated in the tests of which the diameters ranged from 0.8~1.0millimeters.

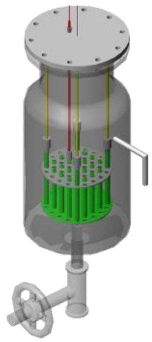

Figure 3 Reaction vessel and the tube bundle assembly

The target assembly directly simulates a real-scale tube size with a pitch-to-diameter ratio. Figure 4 shows the tube bundle assembly, and it was immersed into stagnant sodium with an intermediate leakage rate of steam in 450℃. Steam was injected into the target tubes at $150 kg/cm^2$ pressure and 350℃ temperature.

Figure 4 Model of tube bundle assembly

3. Results and Discussion

Multi-target wastage tests for the modified 9Cr-1Mo steel tube bundle were conducted at a steam leakage rate of 12g/s. In theory, it is enough to cause the surface degradation of not only the main target tube but also its adjacent ones. As shown in Figure 5, steam was injected from the injection nozzle into target tubes disposed in longitudinal, transverse and diagonal directions, respectively.

Figure 6 shows the post-test views of the multi-target wastage test performed with a stagnant sodium condition. As compared with the small-leak test results which only showed pit type wastage, it was found that there were various wastage patterns on the target surface with respect to the target distance between the nozzle and the target tubes. In the case of the transverse direction test particularly, we found several microscopic holes in the damaged area and will try to investigate the reason in the next phase of the experiment.

Although the length of the jet flame, which was calculated theoretically, is longer than the pitch of the heat transfer tubes, there were no apparent traces of wastage on the neighboring target surface. A post-test examination for the damage measurement of all tubes will be carried out by using the ATOS-3D digitizer, which delivers three-dimensional measurement data of the surface examined for general industrial applications.

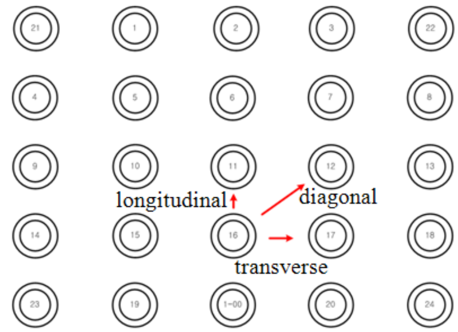

Figure 5 Steam injection directions

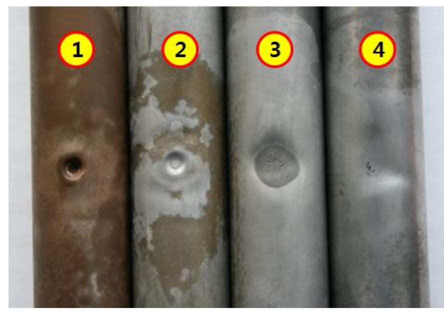

Figure 6 Wastage patterns of target tubes
(1, 2 longitudinal, 3 transverse, 4 diagonal)

4. Conclusions

A series of large-scale wastage tests were conducted to investigate the multi-target wastage behavior of modified 9Cr-1Mo steel used as the SG tube material in the KALIMER-600. The obtained test data will be used to develop the design criteria of rupture propagation due to wastage. It is also expected that the results of this study will significantly contribute to a more detailed evaluation study of multiple tube rupture behavior in the future.

ACKNOWLEDGEMENT

This study was performed under the Nuclear Technology Development Program sponsored by the Ministry of Education, Science and Technology (MEST) of Korea.

REFERENCES

[1] D.H. Hahn et al., KAERI/TR-3381/2007 (2007)
[2] M. Hori, Atomic Energy Review, 18, 708 (1980)
[3] NAOMICHI KANEGAE et al., Nucl. Technol., Vol. 40, 261 (1978)
[4] D. W. Sandusky, Trans. ANS, Vol.19, 106 (1974)
[5] J. R. Donati et al., Nucl. Mater., Vol.54, 217 (1974)