Leak Detection in Insulated Pipe Using Optical Fiber Distributed Temperature Sensor

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1. Introduction

Since nuclear power plants (NPPs) utilize high-temperature, high-pressure coolants and radioactive materials, vapor leak detection and localization are essential to prevent severe safety incidents [1-2]. However, it is generally difficult to detect small leaks early and locate them accurately within insulated pipes due to surrounding insulation materials. Previous methods proposed for leak detection, such as humidity or flow measurement, acoustic detection, and thermography, have shown problems such as slow measurement times, limited number of sensing points and spatial resolution, and installation difficulties [3-4]. To provide better solution for leak detection in NPPs, we propose the use of a high spatial resolution optical fiber distributed temperature sensor based on optical frequency domain reflectometry. Real-time vapor leak detection and localization for insulated pipe was demonstrated experimentally using the optical fiber distributed temperature sensor.

2. Experiments and Results

2.1 Experimental setup

Leak detection test was performed on a small-scale NPP test-bed at KAERI to simulate high-temperature and high-pressured leakage conditions within insulated steam pipe. An optical fiber cable was wrapped in a helical pattern with a 15 cm pitch around the pipe with a 11.5 cm diameter. To prevent heat damage to the fiber, heat-resistant polyimide coated optical fiber, jacketed with a glass braided tube was used in the test. The insulation modules were installed to wrap around the pipe after the fiber cable had been installed.

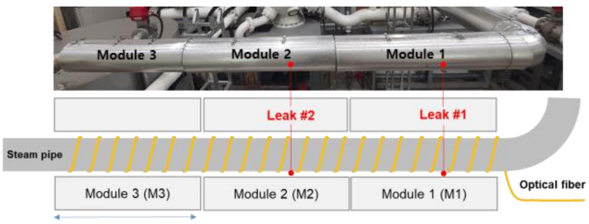
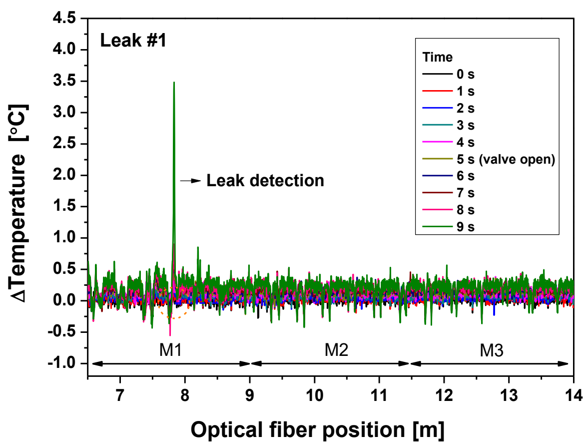


Fig. 1. Experimental setup for high-temperature and high-pressured leak detection using optical fiber distributed sensor.

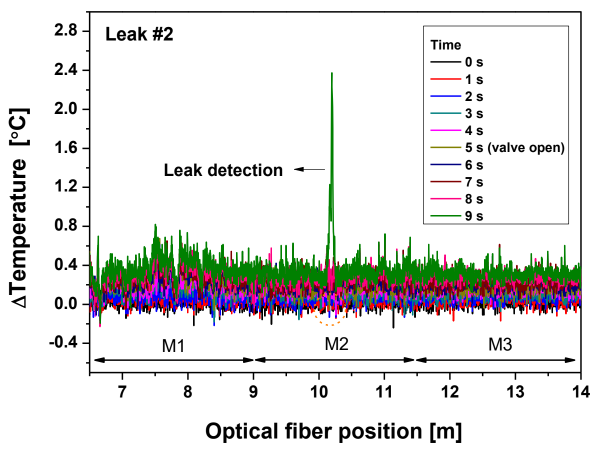
The pipe leakage parts leak #1 and leak #2 were set to be located at the bottom of the insulation module 1 (M1) and module 2 (M2), respectively, as shown in Fig. 1. During the test, temperature sensing data along the fiber cable was acquired by the optical distributed sensor interrogator (ODiSI 6104, LUNA) with a spatial gage pitch of 2.6 mm and a measurement rate of 12.5 Hz.

2.2 Leak detection and localization

The leaks were generated using separated valves on the pipe when pressure and temperature in the pipe was ~3 bar and ~120 ℃, respectively. When the leak valve is opened, high-temperature vapor is transferred through the tubes into the isolation modules, resulting in vapor emission at the specific leak location. Figure 2 shows change in the temperature distribution at different positions of the optical fiber cable wrapped around the pipe before and after the leak events ((a) Leak #1, (b) Leak #2). The temperature at the fiber position adjacent to the leak was found to rise within a few seconds after the leak occurred. In case of leak #1, the temperature at the 7.8 m position of the fiber rose rapidly, indicating that the leak occurred in the middle of the M1 module. Similarly, in case of leak #2, the temperature at the 10.2 m position of the fiber rose rapidly, indicating that the leak occurred in the middle of the M2 module.



(a) Leak #1



(b) Leak #2

Fig. 2. Variation in temperature distribution at different position of the optical fiber cable wrapped around the pipe before and after the vapor leaks: (a) Leak #1, (b) Leak #2.

3. Conclusions

The experimental results showed that the vapor leaks in insulated pipe can be rapidly detected and localized by monitoring temperature variation along the pipeline using the optical fiber distributed sensor technology. Particularly, the configuration of helically wrapping the optical fiber around the pipe demonstrated the ability to detect leak location and direction more precisely. The tighter the pitch of the helical optical fiber structure, the more precisely leak detection can be accomplished.

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