Application of an IR Thermography for Leak Detection of Reactor Coolant

Ye Ji An [a], Kwae Hwan Yoo [a], Ju Hyun Back [a], Man Gyun Na [a*]
[a]Nuclear Engineering Dept., Chosun Univ., 309 Pilmun-daero, Dong-gu, Gwangju, Korea
[*]Corresponding author: magyna@chosun.ac.kr

1. Introduction

In accident situations, recognizing the abnormal signal of the nuclear power plants (NPPs) and performing the safety action by operators need a lot of time. However, to ensure the safety of the NPPs, if reactor coolant pressure boundary (RCPB) leak occurs, the leak detection of reactor coolant should be performed in real-time.

Recently, leak of reactor coolant was identified by a small crack in the small diameter pipe at the bottom of the steam generator.

This accident shows that existing reactor leak monitoring systems are vulnerable to small amounts of leak detection. The identification time for a small amount of leak was also delayed. If the leak detection is delayed, safety actions could be also delayed.

The aging of the NPPs is expected to increase leak of reactor coolant. In particular, stainless steel pipe has a faster crack velocity than carbon steel. So, it is important to detect a small amount of leak early during the nuclear power plant operation.

This study was conducted so that the leak phenomena for small size cracks should be understood by visualizing the leak phenomenon with an infrared (IR) thermography camera. Infrared thermography is one of the non-destructive tests (NDTs) that not only has the high safety but also has a fast testing time [1]. This work will be helpful to develop a new RCPB leak detection method.

2. Theoretical Background

2.1 IR Thermography

An Infrared thermography, one of the NDTs, can detect the surface radiant energy of the object and identify the defect through temperature change images in real-time. The shape and position of defects inside the object can be measured from real-time images obtained with an IR camera [2].

The IR thermography is harmless to the human body and has various application fields, short measurement times and non-contact features. It also has the advantage of easily analyzing the experimental results and improving the work efficiency [3].

Infrared thermography is now used in aerospace, military, composite defect inspection, structural, stress analysis and medical diagnostics [4].

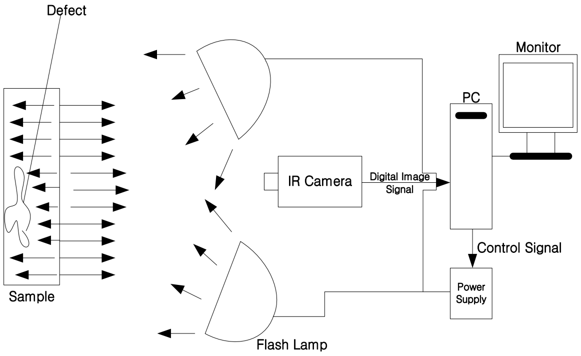

Fig. 1. Diagram for an IR thermography

2.2 Theory

All objects are at the temperature above absolute zero (ºK= -273.15ºC) and emit corresponding radiant energy at that temperature [5].

$$\frac{dR(\lambda,T)}{d\lambda}=\frac{2\pi hc^2\lambda^{-5}}{e^{hc/\lambda kT}-1}$$

(1)

Where

Plank's constant $h=6.626\times10^{-34}\,J\cdot s$

Boltzmann's constant $k=1.380546\times10^{-23}$

Speed of light $c=2.998\times10^{8}\,ms^{-1}$

Eq. (1) is Plank's blackbody radiation theory. There is a simple relationship between blackbody radiation properties (energy intensity, R; wavelength, λ) and blackbody temperature. The amount of wavelength emitted from the blackbody radiator per unit time is determined only by the temperature [6]. The IR thermography shows the temperature image through a correlation between the amounts of energy detected with the temperature.

$$R_t=\sigma T^4 \tag{2}$$

Stefan-Boltzmann's constant:

$\sigma=5.67\times10^{-8}W/\left(m^2\cdot K^2\right)$

Eq. (2) is Stefan-Boltzmann's law that means that the total radiant energy radiated per unit time from the unit area of a blackbody is proportional to the fourth power of the absolute temperature T.

T : Absolute temperature of objects (K)

R_t : Blackbody reflection intensity

Using the Plank's law of Eq. (1) and the Stefan-Boltzmann's law of Eq. (2), the temperature can be measured with an IR thermography camera [7].

$$\varepsilon = \frac{R_a}{R_b} : \text{emissivity} \qquad (3)$$

Where
R_a : Actual emissivity
R_b : Blackbody emissivity

The emission ratio ε of the object and the blackbody surface at the same temperature is expressed by Eq. (3). In this case, an object with ε =1 is called a blackbody.

3. Experiment Methods

In this experiment, the specimens used small diameter pipes with artificial defects. Pipe specimens with artificial crack hole of 0.5mm, 0.7mm, 0.9mm, 1.1mm, and 1.3mm in diameter were used.

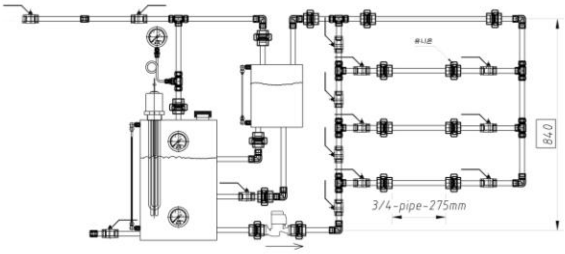

Fig. 2. Experimental drawing

Fig. 2 is an experimental set designed and manufactured for detecting a small amount of leak from a small diameter pipe. The IR thermography camera was placed 1.5m away from the specimens.

The experiment was performed under the conditions shown in the table below.

Table I: Experimental Conditions

Recycling system volume	40L
Diameter of pipe	3/4pipe(Carbon steel)
Temperature of pipe	120°C
Pressure condition	0.1MPa

The valve on the pipe was open for about one minute to model the crack leakage and steam was ejected from the artificial crack hole. And the steam ejecting image was taken using an IR thermography camera.

4. Experiment Results

Depending on the size of the defect, the video image was acquired through an IR thermography camera to detect leak in real-time in the infrared area.

If a line profile is designed in the pipe image, the peak part of the graph indicates a leak.

Fig.3 shows the non-leak image and graph. In addition, Figs.4-8 show the images and graphs when leak is shown using an IR thermography camera.

Compared to Fig.3, Figs.4-8 show that the graphs of the leak positions are different. Small diameter pipes without crack hole and small diameter pipes with crack hole can clearly identify leak in the graph.

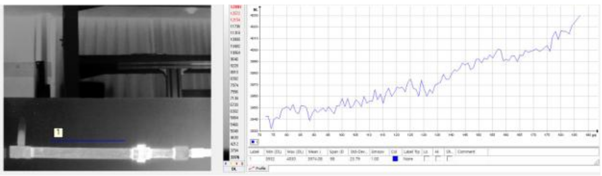

Fig. 3. Image and graph of non-leak

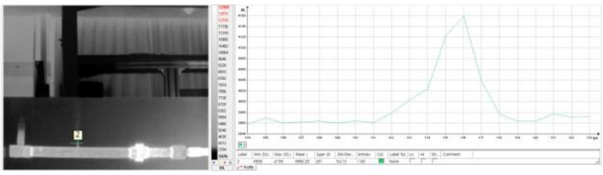

Fig. 4. Image and graph of 0.5mm diameter pipe

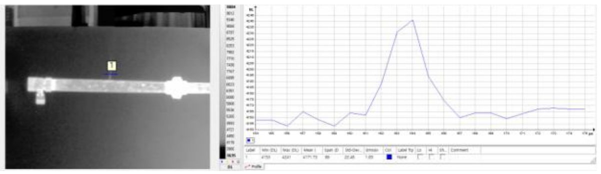

Fig. 5. Image and graph of 0.7mm diameter pipe

Fig.6. Image and graph of 0.9mm diameter pipe

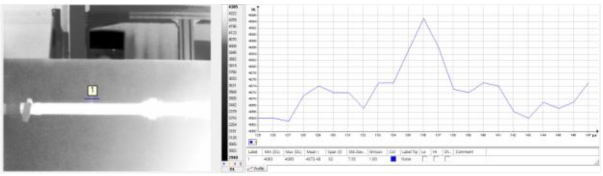

Fig. 7. Image and graph of 1.1mm diameter pipe

Fig. 8. Image and graph of 1.3mm diameter pipe

Experimental results show that even though steam generated from small artificial crack hole in small diameter pipes is not visible in the visible range, it is observed in the IR thermography camera.`

5. Conclusions

In this paper, an IR thermography was used to understand coolant leak phenomena for developing an early detection method of the coolant leak from RCPB, which often occurs in the pipe of existing the NPPs. When an IR thermography camera is used to locate the leak position in a small diameter pipe, steam in the infrared wavelength range is identified through the video. Therefore, the leak identification of small diameter pipe of the NPPS using an IR thermography camera can detect early and visualize small leak.

The IR thermography method can detect a small amount of leak of reactor coolant early and can be helpful to develop a technology to prevent the severe accident leak of reactor coolant. It will also enable the detection of small amounts of leak in low-temperature/non-radiative systems, such as machine cooling water. In addition, the reactor coolant leak is detected early in the initial crack. Thus, it is possible to respond quickly to large break accident. As a result, it is effective to develop technologies to prevent large RCPB leak accidents and to prevent the deterioration of small amount of leak accident from reactor coolant.

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