Feasibility Study on the Development of 2-channel Embedded Infrared Fiber-optic Sensor for Thermometry of Secondary Water System in Nuclear Power Plant

W. J. Yoo [a], K. W. Jang [a], J. K. Seo [a], J. Moon [a], K.-T. Han [a], B. Lee [a*] and B. G. Park [b]
[a]*School of Biomedical Engineering, College of Biomedical & Health Science, Konkuk University, Chungju 380-701, Korea*
[b]*Department of Energy & Environment Engineering, College of Engineering, Soonchunhyang University, Asan 336-745, Korea*
[*]*Corresponding author: bslee@kku.ac.kr*

1. Introduction

In general, it is possible to determine the temperature of any warm object by measuring the emitted infrared (IR) radiation [1,2]. The radiometers using infrared optical fibers are based on the relationship between the temperature of a heat source and the quality and the quantity of an IR radiation [3,4]. To measure physical properties including a temperature, optical fiber-based sensor has many advantages, such as small size, low cost, high resolution, remote sensing and immunity to electromagnetic radiation over conventional electrical sensors [5,6].

In this study, we carried out the feasibility study on the development of an embedded IR fiber-optic sensor for thermometry of the secondary water system in a nuclear power plant. The 2-channel embedded fiber-optic temperature sensor was fabricated using two identical IR optical fibers for accurate thermometry without complicated calibration processes. To decide accurate temperature of the water, we measured the difference between the IR radiations emitted from the two temperature sensing probes according to the temperature variation of the water.

2. Materials and Experimental Setup

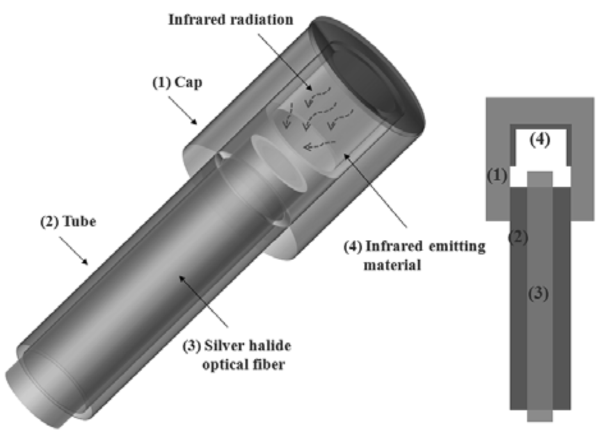

Fig. 1. Structure of a temperature sensing probe.

Figure 1 shows the structure of a temperature sensing probe that is composed of a cap (1), a tube (2), an IR optical fiber (3) and an IR emitting material (4). The cap and the tube are made of stainless steel to protect the IR optical fiber from the water-chemistry and harsh environment of a nuclear power plant.

As an IR optical fiber, a silver halide optical fiber (JT Ingram, PIR 900/1000) is selected for this study. It is reported that this IR optical fiber is non-toxic, non-hygroscopic and biocompatible [7]. The outer diameter of this optical fiber is 1.0 mm, and the cladding thickness is 0.05 mm. The refractive indices of the core and the cladding are 2.15 and 2.13, respectively, and the numerical aperture (NA) is 0.25. The silver halide optical fiber is produced with pure AgCl:AgBr solid solution crystals in a core/clad structure, and the jacket is made of polyetheretherketone (PEEK)-polymer. This IR optical fiber is transparent in a wide spectral range from 4 to 18 μm, and transmission rate is more than 90% in the range from 10 to 14 μm wavelength. The silver halide optical fiber is very flexible and durable over a temperature range from -200 to 250˚C, and the melting point is 415˚C.

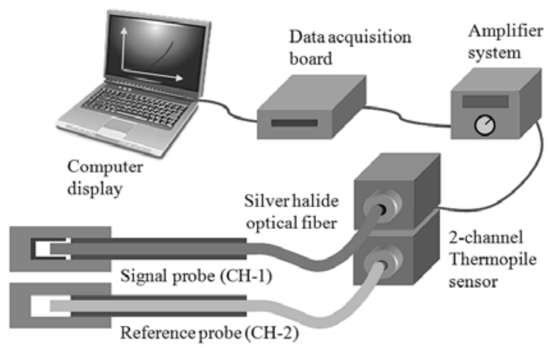

Fig. 2. Experimental setup for measuring the temperature using the embedded IR fiber-optic sensor.

Figure 2 shows the experimental setup for measuring the temperature using the embedded IR fiber-optic sensor. The temperature sensing probes were divided into a signal and a reference probe. The inner part of the cap in the signal probe was coated with high emissivity black paint as an IR emitting material (4) while that of the reference probe was covered with a polished stainless steel cap which has a low emissivity.

Two temperature sensing probes and a thermocouple (Fluke, 54II thermometer) were placed in an oil bath (Samheung Energy, SH-OILWB10) with a temperature uniformity of ± 0.5˚C. The temperature of the water is determined by measuring the intensity difference of IR radiations emitted from two types of IR emitting materials in the caps. The temperature sensing probes are connected to 2-channel thermopile sensor and an amplifier system. There are two identical thermopiles (Perkin Elmer, A2TPMI334OAA060) whose sensing range is from 2 to 22 μm in the thermopile sensor system.

3. Results

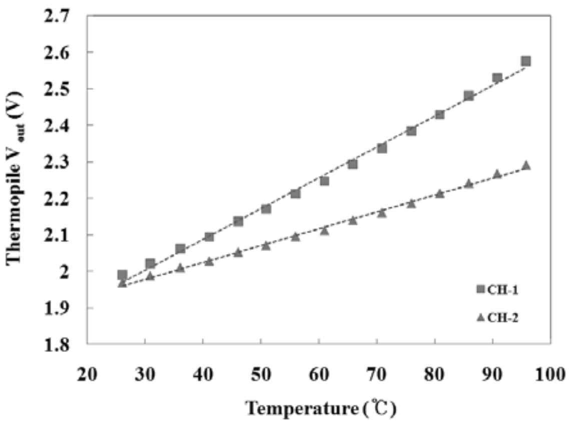

Fig. 3. Responses of the 2-channel thermopile sensor system according to the temperature variation of the water.

Figure 3 shows the output voltages of the 2-channel thermopile sensor system according to the temperature variation of the water. The responses of two channels had a dependence on the IR emissivity of each probe. The gradient of the CH-1 is steeper than that of the CH-2. In addition, the output voltages of the CH-1 are higher than those of the CH-2 because the emissivity of the signal probe is higher than that of the reference probe.

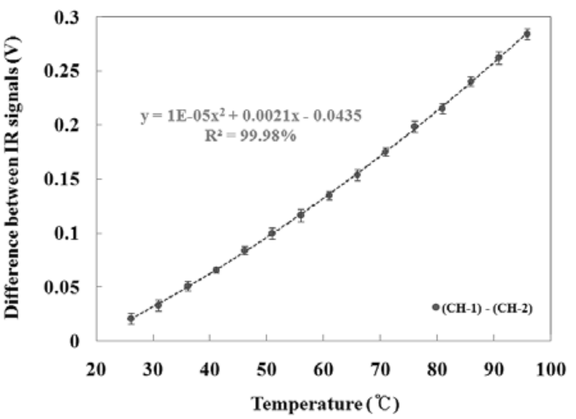

Fig. 4. Relationship between the temperature of the water and the difference in IR signal between the CH-1 and the CH-2.

Figure 4 shows the relationship between the temperature of the water and the difference in IR signal between the two channels. The difference between two IR signals is increased as the temperature of the water increased because the output voltage difference of the CH-1 and the CH-2 is considerably changed according to the warmth of the water. It is shown that there is a linear dependence between the difference in IR signals and the water temperature, and the mathematical form of the best fit line to the curve is also shown in Fig. 4.

4. Conclusions

In this study, we fabricated the embedded infrared fiber-optic temperature sensor using two identical silver halide optical fibers. Thermometry with this sensor is immune to any changes, such as offset voltage, ambient temperature and emissivity of any object. Induced IR radiations which are emitted from the two temperature sensing probes according to the water temperature changes were measured by using of the 2-channel thermopile sensor system. The relationship between the temperature of the water and the difference in IR signals is also determined. Therefore, it could be concluded that temperature can be monitored by measuring the difference between the IR signals of the two temperature sensing probes. Further studies will be carried out to measure temperature in the high pressure/temperature environment by using of an autoclave. Based on the results of this study, it is expected that 2-channel infrared fiber-optic sensor can be developed to monitor the temperature of the secondary water system in a nuclear power plant.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. M20806000154-08M0600-15410).

REFERENCES

[1] J. A. Harrington, Infrared fibers and their applications, SPIE Press, Bellingham, pp. 218-223, 2004.
[2] M. Saito, and K. Kikuchi, Infrared optical fiber sensors, Opt. Rev, Vol. 4, p. 527, 1997.
[3] T. Miyashita, and T. Manabe, Infrared optical fibers, IEEE J. Quantum Electron, Vol. QE-18, p. 1432, 1982.
[4] A. Katzir, H. F. Bowman, Y. Asfour, A. Zur, and C. R. Valeri, Infrared fibers for radiometer thermometry in hypothermia and hyperthermia treatment, IEEE Trans. Biomed. Eng., Vol. 36, p. 634, 1989.
[5] B. Lee, W. J. Yoo, D. H. Cho, K. W. Jang, S.-C. Chung, and G.-R. Tack, Low-temperature radiometric measurements using a silver halide optical fiber and infrared optical devices, Opt. Rev, Vol. 14, p. 355, 2007.
[6] W. J. Yoo, D. H. Cho, K. W. Jang, S. H. Shin, J. K. Seo, S.-C. Chung, B. Lee, B. G. Park, J. H. Moon, Y.-H. Cho, and S. Kim, Infrared radiation thermometer using a silver halide optical fiber for thermal ablation, Opt. Rev, Vol. 16, p. 386, 2009.
[7] S. Sade, and A. Katzir, Fiberoptic infrared radiometer for real time in situ thermometry inside an MRI system, Magn. Reson. Imaging., Vol. 19, p. 287, 2001.