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Research Article

Development of the Noncontact Temperature Sensor Using the Infrared Optical Fiber Coated with Antifog Solution

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This study developed a noncontact fiber-optic temperature sensor that can be installed in a spent nuclear fuel pool. This fiber-optic temperature sensor was fabricated using an infrared optical fiber to transmit the infrared light emitted from water at a certain temperature. To minimize the decrease in the detection efficiency of the fiber-optic temperature sensor due to vapor generation, its surface was coated by spraying an antifog solution and drying several times. The measurement data of the fiber-optic temperature sensor was almost linear in the range of 30~70°C. This sensor could be used as an auxiliary temperature monitoring system in a spent nuclear fuel pool.

1. Introduction

The spent nuclear fuel pool in a nuclear power plant (NPP) is monitored continuously by checking if the key parameters, such as water temperature, water level, and radiation level, are within the prescribed ranges. For example, the technical specifications of Korean NPPs require that the water temperature at the spent nuclear fuel pool be kept within the range 40 to 60°C [1]. Because the current monitoring systems of a spent nuclear fuel pool are AC-powered, they cannot work during a loss of AC power accident, such as the Fukushima Daiichi Unit 4 accident. This led to development of an auxiliary monitoring system in this study, which was powered by a small independent DC power source, to monitor the water temperature.

Optical fiber has advantages such as intrinsic insensitivity to magnetic fields and electromagnetic interference (EMI) and capability to perform remote radiation measurements [2]. Because the spent fuel pool is the high radiation area with high humidity, it is not accessible to workers and the general electronic temperature sensors might not work properly under the condition. Fiber-optic sensor meets such a requirement.

Temperature sensors have been developed in the fields of medicine, oceanography, and other industrial fields. For remote measurements under harsh conditions where general electronic sensors are not used, several studies of fiber-optic temperature sensors have been performed. Sun et al. developed a fiber-optic temperature sensor using the temperature cross sensitivity feature of RI-sensitive devices [3]. Yamada et al. developed fiber-optic temperature sensors at cryogenic temperatures [4]. Zhao and Liao developed a fiber-optic sensor for the simultaneous measurement of temperature and salinity [5]. Seo et al. developed a fiber-optic temperature sensor for measuring the temperature of subsurface water [6].

In this study, the auxiliary monitoring system developed can perform real-time measurements of the water temperature between 30 and 70°C including the temperature range specified by the Korean NPP technical specifications. This study developed a noncontact fiber-optic temperature sensor that can measure the water temperature remotely in real time.

2. Experimental Setup

The noncontact fiber-optic temperature sensor was fabricated using the PIR AgCl : AgBr polycrystalline fiber, which is an infrared optical fiber. Considering that it has been mandated that the water temperature of a spent nuclear fuel pool at Korean NPPs shall be maintained within 40 and 60°C, the normal range of the fiber-optic temperature sensor was set to be between 30 and 70°C.

The fiber-optic temperature sensor measures the water surface temperature by detecting the infrared light emitted from water at certain temperatures [7]. Wien's displacement law could be used to identify the peak wavelength of thermal radiation at a certain temperature:

$$\lambda_{\max} \cdot T = a, \quad (1)$$

where T is the absolute temperature in K, $\lambda_{\max}$ is the peak wavelength of thermal radiation in μm, and a is Wien's displacement constant, which is equal to 2897.8 in μm·K, respectively. From (1), the peak wavelengths corresponding to the temperature range from 30 to 70°C ranged from 8.45 to 9.564 μm.

Because the normal silica optical fibers cannot detect light in the infrared region, the PIR AgCl : AgBr polycrystalline fiber (PIR 900/1000, JT INGRAM) was selected to transmit the infrared light emitted from water in the temperature range 30 to 70°C [8]. Figure 1 shows the trend of light attenuation of a standard PIR AgCl : AgBr polycrystalline fiber as a function of the wavelength. At the infrared wavelengths of 10~14 μm, the light attenuation of the fiber was less than 10%; that is, its light transmission rate was 90% or more.

The PIR polycrystalline fiber is nontoxic and quite flexible [9]. Table 1 lists the properties of the AgCl : AgBr polycrystalline fiber chosen in this study.

When measuring the water temperature with a fiber-optic temperature sensor, the vapor generated by the change in water temperature can decrease the detection efficiency of the fiber-optic temperature sensor [10]. In the experiment where an oil bath was used, fogging began to occur at 40°C or more. Before long, water drops formed on the optical fiber surface. To prevent this, the surface was coated with an antifog coating solution. The main ingredients of an antifog solution are surfactants.

The surfactants are compounds that lower the surface tension between two liquids or between a liquid and a solid and can be classified as cationic, anionic, and nonionic. Nonionic surfactants are generally used as antifogging solutions because of their nonirritating characteristics [11]. This study also selected nonionic surfactants as an antifogging solution. The infrared optical fiber's surface was coated by spraying an antifog solution and drying several times. In addition, a vibration motor (2.4~3.6 V, OEM) was attached to the infrared optical fiber to shake off the water drops that can form on the optical fiber surface.

Figure 2 shows the experimental setup of the noncontact infrared fiber-optic temperature sensor. The temperature sensor detected the water temperature in an oil bath (WHB-6, DAIHAN) with the water temperature being changed by 5°C in the range 30~70°C. The distance between the infrared optical fiber and the water surface was 1 cm. As a reference, the water temperature in the oil bath was also detected using a digital infrared thermometer (IR-302, CUSTOM Corporation). Infrared light was passed through the infrared optical fiber and transmitted to the thermopile-type photodiode detector module (TH-20-H, Electro-Optic System Inc.) that was powered by an independent small DC power source (30V, DP30-03A, Toyotech). Measured data was acquired from DAQ devices (NI USB-6212 BNC, National Instruments) and was analyzed using the LABVIEW program.

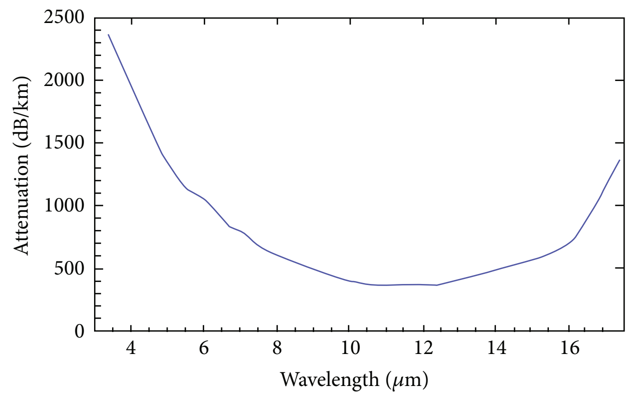

Figure 1: Wavelength per attenuation.

Table 1: Properties of the AgCl : AgBr polycrystalline fiber.

Standard PIR AgCl : AgBr polycrystalline fibers	
Transmission range, μm	4–18
Core diameter, μm	860 ± 20
Core material	$AgCl_{0.25}Br_{0.75}$
Clad diameter, μm	1000 ± 0.25
Clad material	$AgCl_{0.50}Br_{0.50}$
Numerical aperture	0.30 ± 0.03
Operating temperature, °C	$-270 < T < 150$
Protective tubing	PEEK

3. Results and Discussion

Figures 3 and 4 show measurements by the fiber-optic temperature sensors of different lengths with and without antifog solution coating. The lengths of the fiber-optic sensors were 1 m and 3 m, respectively. The figures show that fogging has influenced the temperature measurements starting from 40 in Figure 3 and 35°C in Figure 4, respectively. The results of the temperature measurements were represented in the voltages and were almost linear in the range 30~70°C. The correlation coefficients (r^2) between the water temperature (x) in the oil bath and the output voltage (y) of the temperature sensor were 0.997 and 0.986, respectively.

This study developed and characterized a noncontact fiber-optic temperature sensor powered by a DC power source to examine the feasibility for the remote detection of the water temperature. As shown in Figures 3 and 4, the temperature sensor showed feasibility in detecting the water temperature remotely. Therefore, it is expected that a noncontact infrared fiber-optic temperature sensor can be used as an auxiliary water temperature monitoring system in a spent nuclear fuel pool, even in emergencies, such as a loss of AC power accident.

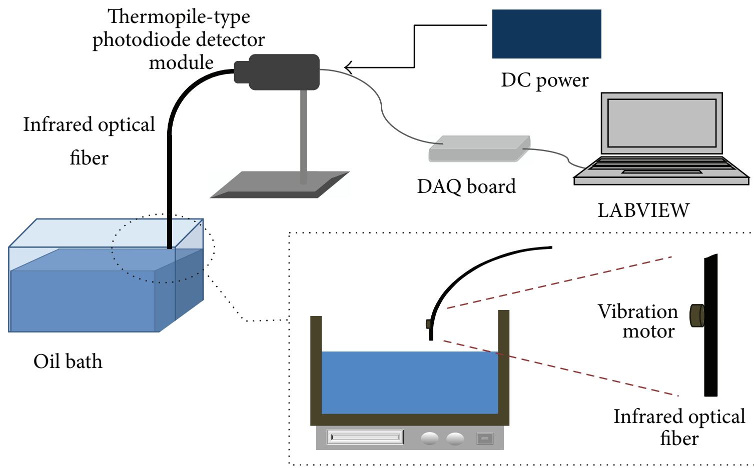

Figure 2: Experimental setup.

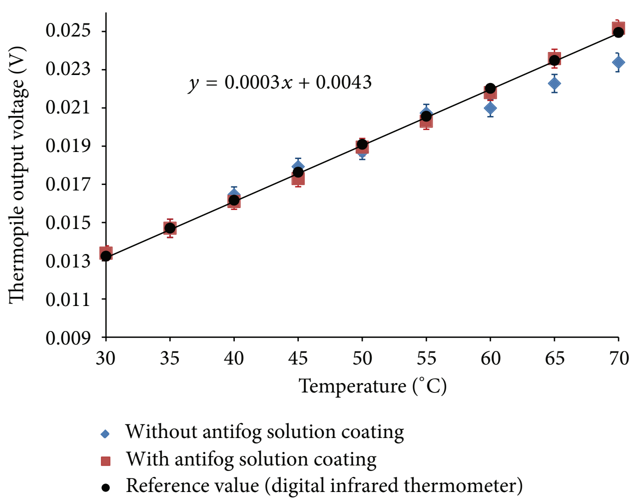

Figure 3: The temperature measurements by the temperature sensor with the infrared optical fiber being 1 m.

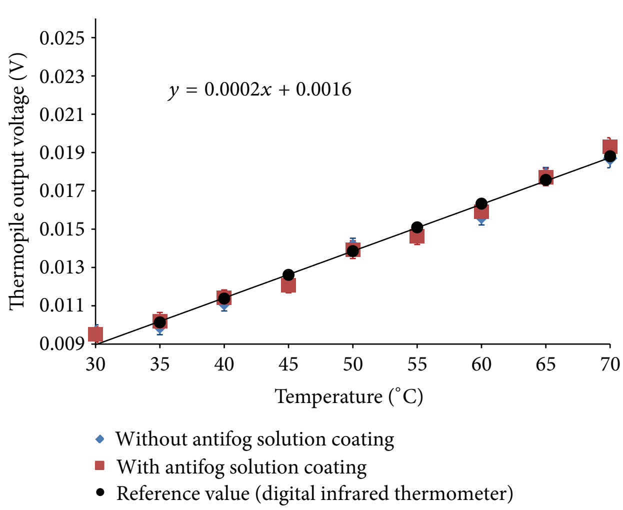

Figure 4: The temperature measurements by the temperature sensor with the infrared optical fiber being 3 m.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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