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Development of a fiber-optic humidity sensor for the online monitoring of coolant leakage

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1. Introduction

Leakage detection and monitoring in nuclear power plants are performed by a number of different methods at present. Although quantitative leakage determination is possible with condensate flow monitors, sump monitors, and primary coolant inventory balance, these methods are not adequate for finding local leakages [1]. Also, the systems for inspecting damage and defect of various kinds of pipes in a nuclear power plant utilize thermal imaging, ultrasonic, and acoustic methods. However these systems are not adequate for detecting local leakages especially from the pipes and they are often not very sensitive. Normally, to detect leak locations is very difficult if the leak occurs at a point which is not specifically monitored in a nuclear power plant. This means that a large number of sensors need to be employed if all points of interest are to be covered. The coolant leakages can induce big accidents such as sudden shutdowns of reactor, a radioactive contamination of the environment and radiation exposure of workers. Therefore, the efficiently management of coolant leakage in a nuclear power plant is very important to ensure the safe of workers and preserve the structural operation of a facility [2,3]. In this study, we developed a fiber-optic humidity sensor (FOHS) for early detection of coolant leakage before their developing into pipe breaks or ruptures.

2. Methods and Results

2.1 fabrication of sensing probe of FOHS.

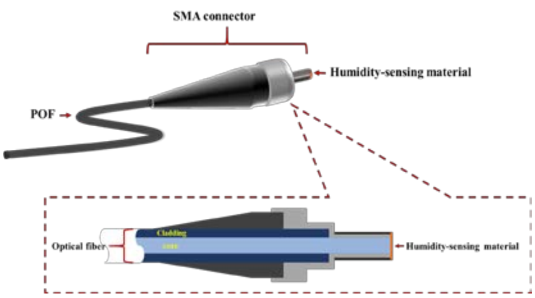

Fig. 1. Internal structure of the FOHS.

We fabricated a FOHS, by using subminiature version A (SMA) connectors a plastic optical fiber (POF) and a humidity-sensing material as shown in the figure 1. To transmit light signals, we used a step-index multi-mode POF (GH4001, Mitsubishi Rayon). The thickness of a cladding is 0.02mm consists of a fluorinated polymer which has the refractive index of 1.402. The core whose diameter is 1 mm consists of polymethyl methacrylate (PMMA) which has the refractive index of 1.492. The numerical aperture (NA) of the POF is 0.5. The end of fiber was coated with the humidity-sensing material which is synthesized with a mixture of polyvinylidene fluoride (PVDF), dimethyl sulfoxide (DMSO), hydroxyethyl cellulose (HEC) and distilled water. This humidity-sensing material has a characteristic changes the refractive index in accordance with changes of the relative humidity (RH). The refractive index of this material can be determined by the weight ratio of PVDF in DMSO and HEC in distilled water. Table 1 shows the mixing ratio of PVDF and HEC by weight to determine the optimal humidity-sensing material [4].

Table. 1. Mixing ratio of PVDF and HEC.

	PVDF:HEC
Sample 1	1:4
Sample 2	1:3.5
Sample 3	1:3
Sample 4	1:2.5
Sample 5	1:1.7

2.2 Experimental setup

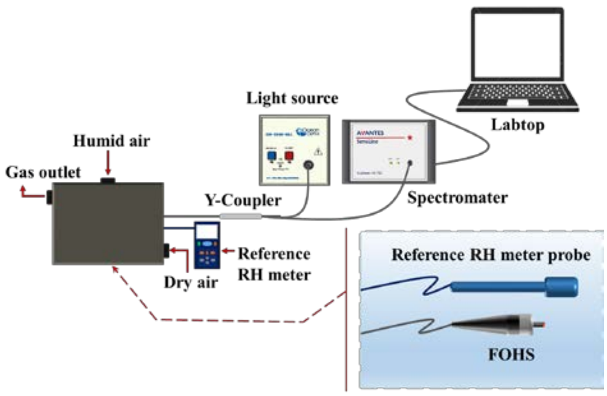

Fig. 2. Experimental setup for measuring humidity using the FOHS.

The experimental setup for measuring humidity using the FOHS is shown Fig. 2. The whole sensing structure is put into the specially designed humidity chamber which is connected to an air-controllable humidification driver.

The RH value in the humidity chamber can be detected by the reference RH meter (TES-1364, Tes Electrical Electromic). We used halogen white-light source (DH-2000-BAL, Ocean Optics) and measured optical intensity of light signal, which is reflected by Fresnel reflection, through the spectrometer (AvaSpec-HS1024, Avantes). Then, by using the fiber-optic Y-coupler (IF-562, Mitsubishi Rayon), we connected the light source, spectrometer and the FOHS. The Fresnel reflection, generated at the interface between the humidity-sensing material and the POF in the end of sensing probes, is changed by varying the refractive index of the humidity-sensing material according to the RH [5]. Through this experiment, we could select the optimal mixing ratio of PVDF and HEC and evaluate the performance of FOHS.

2.3 Results

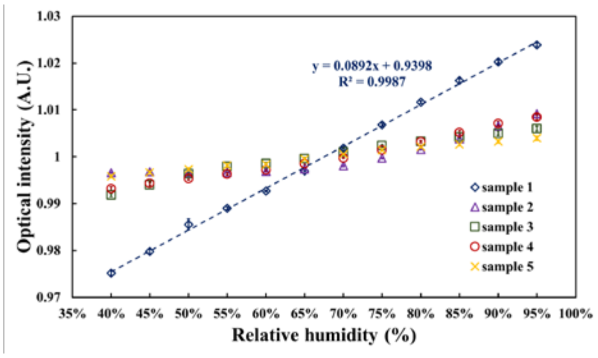

Fig. 3. Comparison of the optical intensities of the FOHS with five mixing ratios of the samples according to the humidity variations in the humidity chamber.

Figure 3 shows the comparison of the optical intensities of the FOHS with five mixing ratios of the samples according to the humidity variations in the humidity chamber. Sample 1, shows a very good linearity and high sensitivity as shown in figure3.

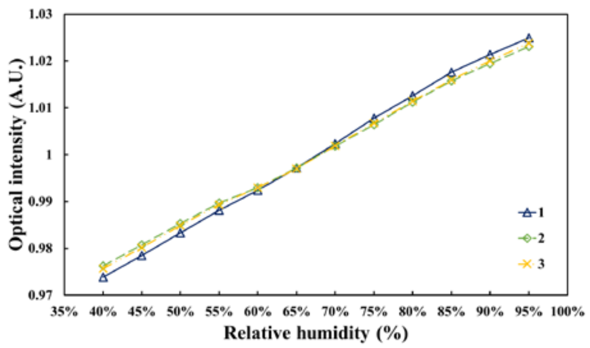

Fig. 4. The repeated measurements of optical intensities with a sample 1.

Figure 4 shows the repeated measurements of optical intensities with a sample 1. We measured RH using the FOHS 3 times in the range of 40 to 95% humidity. Through the repeated measurements, we could confirm that the humidity-sensing material of sample 1 show the pretty stable results and it can be adopted as a sensor tip material of the FOHS. At all measuring points, all data are in the rage of 0.0007% to 0.23% error of measurements.

3. Conclusions

In this study, we fabricated the FOHS using a POF, a SMA connector, and the humidity-sensing material. The humidity-sensing material was synthesized with a mixture of HEC in distilled water and PVDF in DMSO and was coated with the end of fiber. The coated humidity-sensing material acts as a reflector whose refractive index decreases with the rise in the humidity and thus allows more light to be reflected. Through the experimental results, we confirmed that the proposed FOHS is possible to measure the RH. Especially, the sample 1 has a high sensitivity and a good linearity within the measurement range of 40 to 95% RH. It is expected that the FOHS can be efficiently used in early detecting the coolant leakage. Further studies are planned to develop the distributed multi-channel fiber-optic temperature and humidity sensor system for detection and monitoring of coolant leakages in nuclear power plants.

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