AN IMPROVED DISTRIBUTED OPTICAL SENSOR FOR DETECTION AND LOCALIZATION OF LIQUID HYDROCARBONS.

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Abstract: An improved sensor capable of detecting and locating liquid hydrocarbon leaks on long pipelines is presented. A technique to optimize the performance of microcurvature optical sensor response is developed by modifying the cross-linking density of the elastomer employed.

1. INTRODUCTION.

The basic design of the sensor is shown in Fig. 1. The sensor is formed by an elastomeric cable reinforced by a steel wire of 200.0 ± 5.0 μm in diameter. An optical fiber is placed into the cable at 1.5 ± 0.05 mm of its center. In the opposite side of the optical fiber aluminum mesh is also placed. Finally, a stainless steel wire of 200.0 ± 5.0 μm in diameter is coiled at the exterior of the cable. The experimental prototypes were designed to detect gasoline leaks; therefore, a low polarity elastomer was chosen for this study. A ramified Polybutadiene (BR), commercialized by Negromex S.A., as Solprene-200, was chosen for this purpose. Dicumyl peroxide (DCP), provided by Vanderbilt Inc., was employed to reticulate the BR. Five different concentrations of DCP were used: 0.05, 0.1, 0.15, 0.2 and 0.25 % w/w. In order to manufacture the sensor, a Brabender single-screw laboratory extruder was employed using a coating die with a mouth of 5 mm in diameter. A sensor of approximately 6 mm in diameter was obtained, with the optical fiber and reinforcement wire already integrated. In order to achieve the cross-linking reaction, the cable was heated at 175°C during 20 min in a forced-convection stove.

Forty-five sensor samples of 300 m were fabricated using cables prepared with previous formulations (three samples for each formulation). The samples were tested by direct immersion in gasoline at room temperature. The test zone was 30 cm long and was always located at a distance of 150 m from the beginning of the sensor. Each test was stopped after 60 min of immersion.

2. RESULTS

Figure 2 shows a sensor sample (where the aluminum mesh was removed to improve the view of the fiber position). In photo 2.a the original sensor is shown, while in photo 2.b

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it is observed after 20 min of direct submersion in gasoline. In the first photograph, a very light bending of the optical fiber is observed inside the sensor, which produces a small initial attenuation, while in photo 2.b it is observed how the optical fiber bends at the area directly below of the helicoidal wire, maintaining practically its form through the section between each wire pitch. It is important to mention that without a mesh the attenuation diminishes almost a half. Therefore, the optical fiber bending of the following results must be more important that that observed in the present figure.

Fig. 3 shows the attenuation in the optical fiber due to sensor swelling by gasoline as a function of the DCP content, at different immersion times. It is observed the existence of an optimal reticulation level for which the response is the fastest. The percentage of DCP for which the attenuation has a maximum is roughly of 0.15 % w/w for series 1 and 2, and of 0.20 for series 2.

The performance of this type of sensors depends of a number of factors, such as its geometry, the kind of optical fiber (multi or single mode), the wavelength of the optical signal, the wire pitch, the elastomer characteristics, etc. Of all these factors, perhaps the less studied is the elastomer (or more generally the polymer). Indeed, in almost all works related to this subject only mention the polymers used but no reference is made about their morphologies. In the present work, we stressed the importance of this factor, which is determinant for an optimal performance of this type of sensors, and in particular, its level of reticulation.

There are a number of different ways to reticulate an elastomer. Reticulation could be done by physical means (for example irradiating the elastomer with beta rays) or by chemical ones (for example using peroxides as the DCP employed in this work). However, the fundamental structural factor, as previously mentioned, is the cross-linking density $\rho_{c\text{-}l,}$ obtained. This parameter tells us how much an elastomer has been reticulated and it is independent of the method employed. Indeed polymers with the same cross-liking density have the same properties no matter if it was physically irradiated or chemically treated. Therefore, in order to explain the behavior of our elastomer we will employ this density as the main variable in the subsequent graphs.

3. CONCLUSIONS

In the present study, the performance of distributed optical sensors based on fiber bending by a swelled elastomer was studied. More specifically, the influence of the elastomer micro-morphology on the sensor performance was examined. It has been found that the sensor performance may be optimized by finding the condition where the developed osmotic pressure is large enough to surpass the resistance of the optical fiber to be bended, and where the elastomer may absorb enough solvent to bend the fiber at the level required.

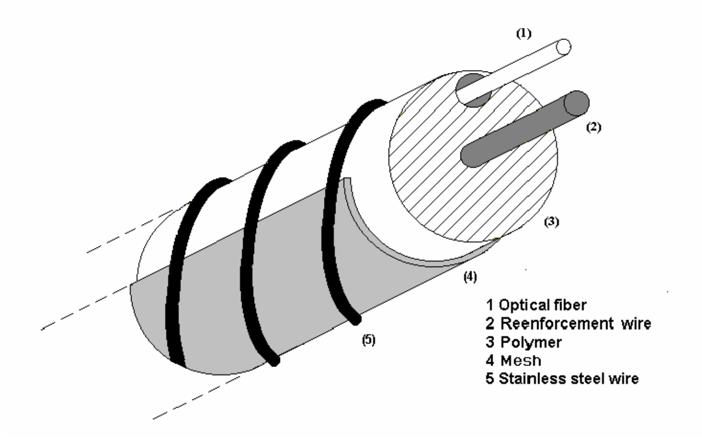
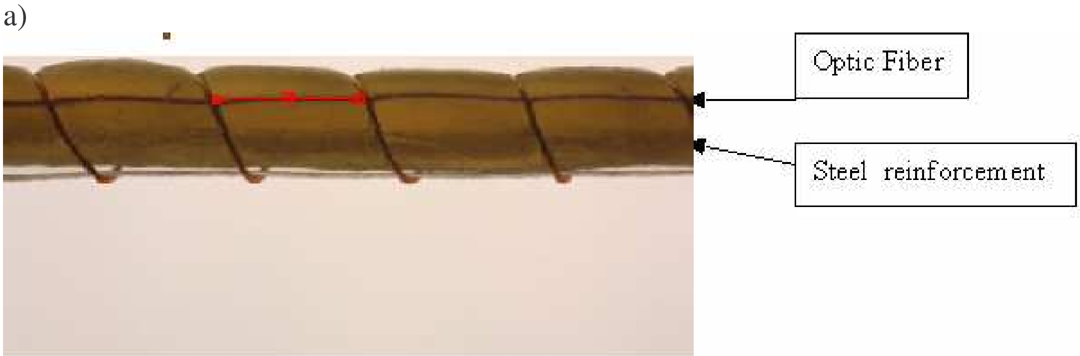


Figure 1: Sensor model.

a)



b)

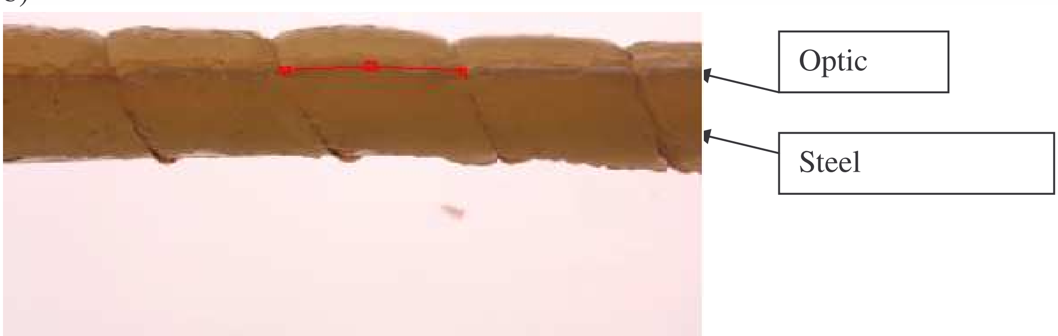


Figure 2: Photographs of the sensor before and after to immersion in gasoline. a) Original state, b) after 20 min of immersion.

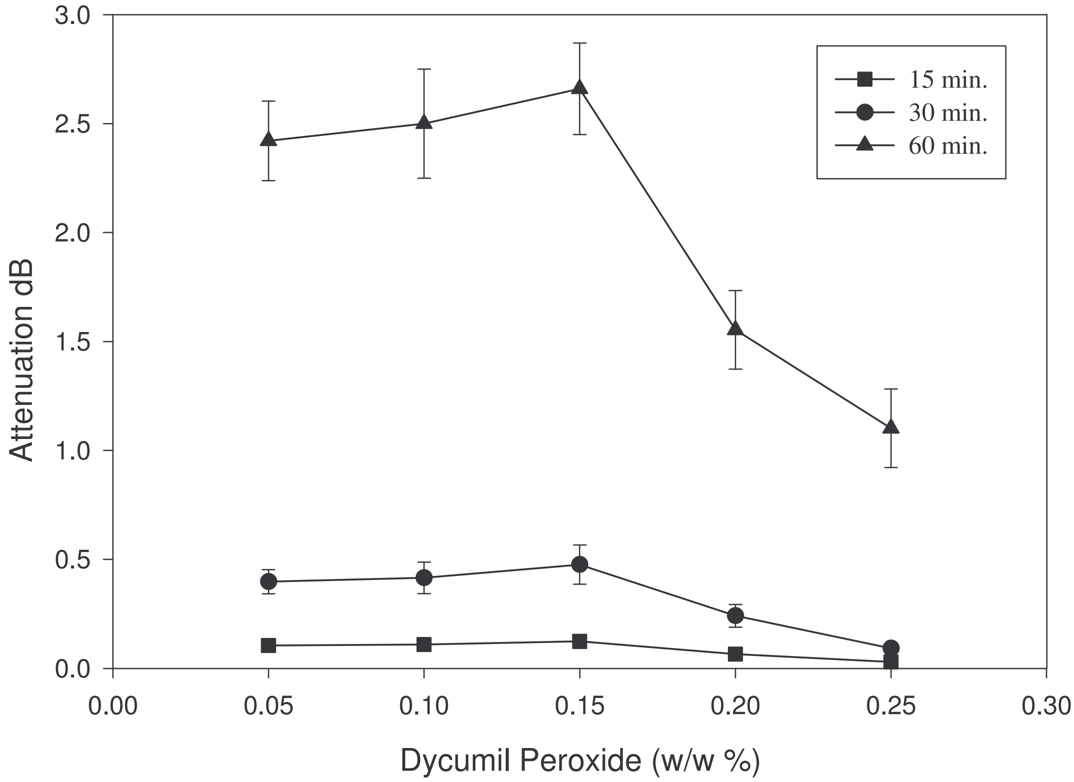


Figure 3: Attenuation of sensors of series 1; after 15, 30 and 60 minutes of immersion in gasoline.