Regresa al Indice

NEW DISTRIBUTED OPTICAL SENSOR FOR DETECTION AND LOCALIZATION OF LIQUID HYDROCARBONS. PART II: OPTIMIZATION OF THE ELASTOMER PERFORMANCE.

Mónica Mendoza, Antonio Carrillo and Alfredo Márquez*
Centro de Investigación en Materiales Avanzados, Miguel de Cervantes #120, Complejo Industrial Chihuahua, Chihuahua, Chih. 31109, México.

ABSTRACT

This paper reports the second part of a work that introduces and describes the testing of a new optical distributed sensor [1]. This new sensor is capable of detecting and locating liquid hydrocarbon leaks on long pipelines. In the first part of this work a number of advantages of this new design were presented. The present part deals specifically with the influence of elastomer preparation on the performance of this sensor. The results show that the optimal sensor response is obtained when the osmotic pressure developed by the elastomer due to hydrocarbon absorption and the swelling of the elastomer are balanced. Therefore, by modifying the cross-linking density of the elastomer it is possible to optimize the sensor performance, by finding the condition where the pressure against the fiber is large enough to surpass the resistance of the optical fiber to be bended and, at the same time, the elastomer absorbs enough solvent to bend the fiber at an optimum level.

INTRODUCTION

The present work deals with the influence on the performance of the sensor due to the elastomer cross-linking density and additives content. It is important to stress that these parameters are not only valid for our design but also for other sensors that use the same principle. In this type of sensors, the main force to bend the fiber is the osmotic pressure produced into the elastomer by the absorption of the liquid. The magnitude of this pressure is dictated by the interaction constant χ_{12} of the elastomer-solvent system as well as the cross-linking density of elastomer molecules ($\rho_{c\text{-}l}$). Concerning the roll of the additives, it is important to mention that an elastomer is rarely processed in its original state; normally, some processing aids are used as plasticizers, lubricants, antioxidants, etc. These substances allow a convenient flow during the processing and reduce the material degradation. However, these additives may also have an influence on the behavior of the sensor. This influence is specially considered in the present study.

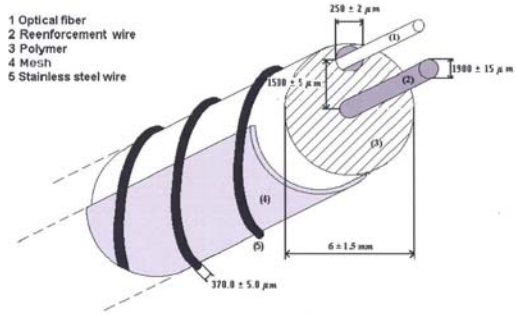


Figure 1. Sensor Model

* Corresponding autor. E-mail address: alfredo.marquez@cimav.edu.mx (A. Marquez)

Regresa al Indice

EXPERIMENTAL

The experimental prototypes were designed to detect gasoline leaks; therefore, a low polarity elastomer was chosen for this study. A ramified Polybutadiene (BR), was chosen for this purpose. A dicumyl peroxide (DCP), 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. Three different series of formulations were prepared: the first without additives, the second has two plasticizers; stearic acid (2% w/w) and calcium stearate (4% w/w), and the third has the same proportion of plasticizers that the previous one plus 5% w/w of naftenic oil. In order to manufacture the sensor, a Brabender single-screw laboratory extruder was employed using a coating die with a mouth of 5.0 mm in diameter.A sensor of approximately 6.0 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 300.0 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.

Evaluation of the osmotic pressure.

The effect of the cross-linking density over the osmotic pressure and equilibrium swelling of a gel has been approximately described by Flory and coworkers [2,3]. These models establish that the osmotic pressure (π) of a swelled gel is approximately evaluated by the following expression:

$$\pi = k\, T\, Nv\, (\phi^{1/3} - a\phi/\, 2) \qquad (1)$$

Furthermore, we have considered that the cross-linking density could be evaluated as:

$$\rho_{c\text{-}l} = M_0/M_C = Nv\, M_0/Nav\, \rho \qquad (2)$$

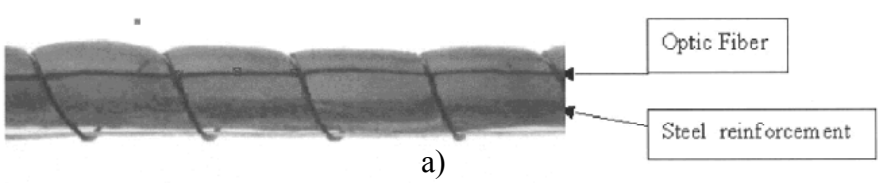
where M_0 is the molecular weight per structural unit, Mc is the molecular weight per cross-linked unit, Nav is the Avogadro number and ρ is the elastomer density.

The osmotic pressure has the following dependence to the cross-linking density:

$$\pi = \rho_{c\text{-}l}\, (k\, T\, \rho\, Nav)\, (\phi^{1/3} - a\, \phi/\, 2)/\, M_0 \qquad (3)$$

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 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.



a)

Regresa al Indice

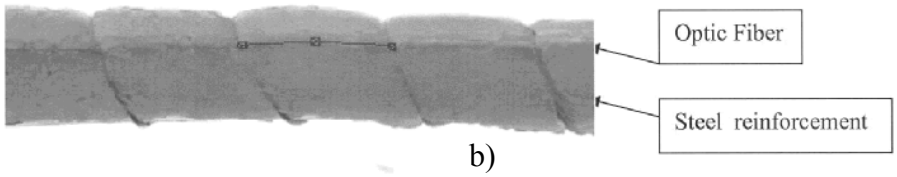


Figure 2. Photographs of the sensor before and after to immersion in gasoline; (a) original state, (b) after 20 min of immersion.

DISCUSSION

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, the authors only mention the polymers used but no reference are 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.

Figs. 3-5, show the results on fiber attenuation, elastomer swelling ($1/\phi$) and the corresponding osmotic pressure due to the absorption of gasoline as function of the reticulation density $\rho_{c\text{-}l}$. The data corresponding to series 1 are plotted in Fig. 3. A maximum attenuation is obtained for a reticulation density ($\rho_{c\text{-}l}$) of 2.1 x 10^{-2}. It is interesting to note that, until this point, the attenuation rises when the osmotic pressure increases; this is normal because at larger pressures the fiber bending is more important. However, at higher values of $\rho_{c\text{-}l}$ the elastomer swells less and then it fails to deform the fiber. Similar conclusions could be drawn from the subsequent Figure 4.

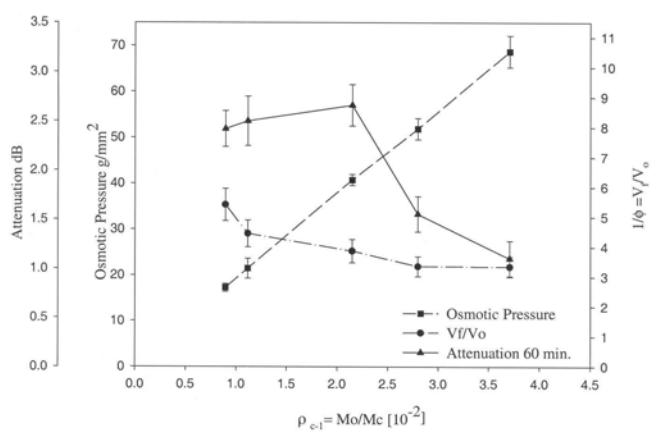


Figure 3. Attenuation, swelling and osmotic pressure developed after 60 min of immersion in gasoline of the samples of series 1.

It is interesting to observe that for the two first series, the attenuation grows when osmotic pressure rises until that the swelling falls bellow a value of 4, and at this point the attenuation falls when the swelling diminishes. Therefore, under this threshold the increase in volume of the elastomer starts to be insufficient to bend the fiber at an optimal level.

Regresa al Indice

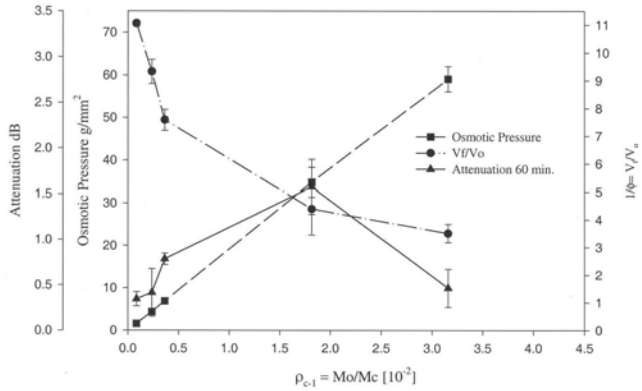


Figure 4. Attenuation, swelling and osmotic pressure developed after 60 min of immersion in gasoline of the samples of series 2.

Similarly, for series 3 the decrease of the attenuation starts when the swelling falls below a value of 6. It must be mentioned, however, that the mineral oil introduced in series 3 is useful to reduce the viscosity of the melt but also imparts a high flexibility to the solid elastomer. In the case of the last samples, a visual inspection of the bending process reveals that the elastomer circumvents the optical fiber instead of bending it, producing a lower response.

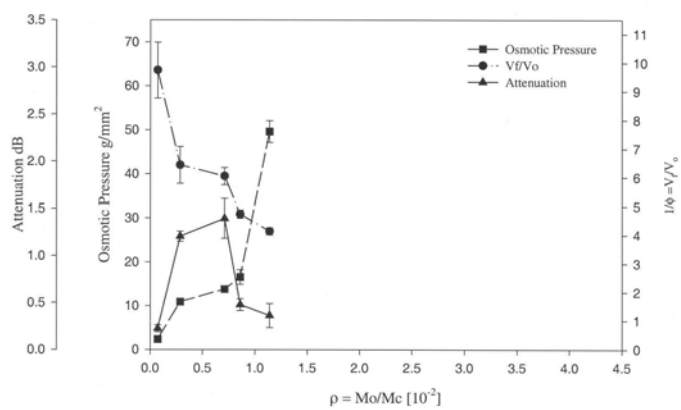


Figure 5. Attenuation, swelling and osmotic pressure developed after 60 min of immersion in gasoline of the samples of series 3.

Also, it is interesting to note that the samples of series 1 apparently keeps a large attenuation on the optical fiber even when the swelling is low.

The previous visual inspection also revealed that the surface of the elastomer of this last series remains practically undeformed due to the rigidity imparted by the reticulation. Indeed, this could be evaluated by the increase of its elastic (E) and shear (G) modulus. This modulus varies with the cross-linking density $\rho_{c\text{-}l}$ in the following way [4]:

$$E = 3\, \rho_{c\text{-}l}\, R\, T\, \rho / M_0 \; ; \qquad G = \rho_{c\text{-}l}\, R\, T\, \rho / M_0 \qquad (4)$$

Regresa al Indice

Therefore, it is normal that the samples with a large reticulation are also the ones that more efficiently bend the optical fiber.

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.

REFERENCES

1. A. Carrillo A, E. Gonzalez, A. Rosas and A. Marquez, "New distributed optical sensor for detection and localization of liquid leaks". Part I. Experimental studies, *Sensors and Actuators A*, 3298, (2002) pp. 1-7.
2. P.J. Flory, Principles of polymer chemistry, Ithaca, *NY: Cornell University Press*, 1953.
3. P.J. Flory, J. Rehner Jr., *J. Chem. Phys*., 11 (1943), pp.521.
4. L.R.G. Treloar, The Physics of Rubber Elasticity, *Oxford University Press, Oxford*, 1958.