In Situ Refraction Index of Liquids measurement using Polymer Optical Fibers

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ABSTRACT

A device for the measure of index of refraction of liquids in situ based on polymer optical fibers (POFs) was demonstrated. It consists in a sensor head of three passive POFs where two are coupled to two detectors and an electronic unit for the differential measure of signals. A differential operating principle is utilized to reduce noise such as light intensity fluctuation. The device was successfully checked measuring refraction index changes of the water with different concentrations of sugar, salt and alcohol.

Keywords: Liquid Refractive Index Measurement, Polymer Optical Fiber,

1. INTRODUCTION

The index of refraction of liquids has been measured by several methods. This can be determined starting from the minimum angle of deviation of the sheaf that she/he spreads through the contained liquid in a triangular cell [1]. The measure of the angle of deflexion of a sheaf laser that crosses a contained liquid in a prism in form of V is used to determine the index [2]. Method more complex using assembly interferometers has also been developed [3]. Refractometer based on fiber optics has been proposed to measure indexes of different liquids [4-5]. All these assemblies are not appropriate to carry out index measures *in situ*. In certain work domains, be it in research laboratories or in industry, it is necessary to know the refractive index or concentrations of liquid. For example, in the industry of foods is necessary to know the concentration of sugar, salinity or alcohol in liquid substances. The refractive index depends of the concentration of the elements of the liquid. For these operations it is desirable to have a simple and direct device of measure of refractive index, besides being compatible and inert with the liquid. Polymer optical fibers are very attractive for the connections of short distances and they possess important advantages regarding the glass fiber. The POFs is manufactured with a great diameter, great numerical aperture, they are easy to manipulate, the extremity components are of low cost and they have an excellent flexibility. Taking advantage of the chemical properties of the POFs a sensor has been developed in a previous work. [6].
In this work, a sensor able to measure the index of refraction of liquids is presented based on POFs technology. The theoretical pattern and the calculations associated to a system of three fibers are analyzed. The construction of the sensor and the experimental results of different liquids are presented.

2. OPERATION PRINCIPLE

A simple system of measure of the index of refraction of a liquid can be formed axially by one emitting and other one receiving fibers separate and submerged in a liquid. The variations of the index of refraction of the liquid modulate the intensity of spread light. In this case, the intensity of light coupled in the receiving fiber depends on the parameters of the liquid means, the propagation loss, the transmission coefficient Fresnel in the interfaces and of the geometric factor of the separation among the fibers. This last parameter is independent of the attenuation and it can be modeled in a simple way, introducing the characteristics of the fibers and the index of refraction of the medium. Several previous works have provided solutions to this case [7]. because the index of refraction of the liquid is sensitive to the variations of the coupled luminous power, other factors can also affect also the power measured by the detector, these they are bends of the fibers, variations of optic power of the source of light, losses of joining source-fiber and variations of temperature. With the purpose of avoiding the influence of these factors and the inaccuracy of measure of the index, we have

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developed a system of three fibers. The outline of the measure system is shown in the figure 1. The receiving fibers displaced axially among them with regard to the axis of the fiber radio station allows to carry out a measure of differential optic power, annulling the undesirable factors that perturb the measure of the index of the liquid therefore. The calculations carried out here are referred to a step index multimode fiber optic. We adapt to the fiber particularly POF-PMMA of 1 mm of diameter.

Let us consider a recipient that contains a liquid of index n_ℓ. In this liquid a system of three optic fibers is introduced. The optic fibers have been fixed inside a compact support with the help of plastic, this it is illustrated in the Fig. 1. Two receiving fibers separate and displace with axially with regard to the emitter fiber. The power coupled in each one of the fibers can be expressed as the product of three factors: Fresnel transmittance at end-faces; total light coupled to the receiving fiber from a exit cones originating at the end of the emitter fiber; the attenuation of light in the medium filling the gap between the fibers [4]. The power coupled in receiver fiber in a medium liquid (n_ℓ) is given,

$$P(n_\ell) = I\,C\,f(n_\ell)\,T(n_\ell).\exp(-\alpha z) \qquad (1)$$

where I is the intensity of light of the emitter fiber, C is a constant that represent the attenuations of the fibers, T(n) it is the coefficient of Fresnel of transmittance of the ends of the fibers, $f(n_\ell)$ is a geometric factor that models the front of wave of propagation of the light in the liquid means in function of the distance z and of the index n_ℓ. Because the receiving fibers are displaced, the power coupled in each one of them is different. Designing a proper arithmetic divider the I and C coefficients of equation (1) are cancelled. Finally, the quotient of the powers coupled by the two fibers is given by:

$$\frac{P_1(n_\ell)}{P_2(n_\ell)} = K\frac{f_1(n_\ell)}{f_2(n_\ell)} \qquad (2)$$

where K is a constant quantity of the attenuation of the fibers.

This way it has been possible to design a simple system to measure the index of refraction of liquids. Based on the referred equation 2, a simple arrangement fiber system to measure the refraction-index of liquids is designed and constructed.

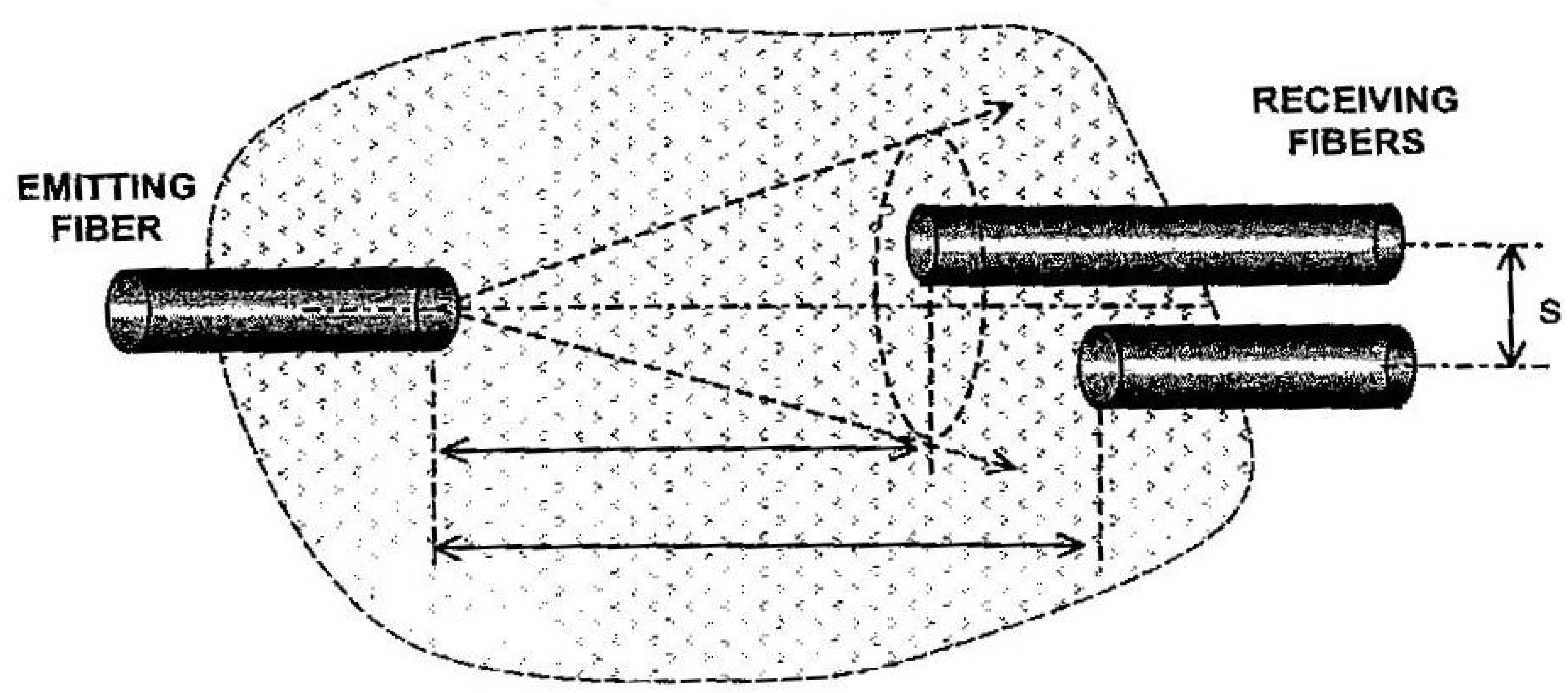

Figure 1. Schematic diagram illustrating the principle of light coupling between three axially separated multimode optical fibers with a medium of refractive index n_ℓ filling the gap.

3. MEASUREMENT AND RESULTS

The carried out measure system uses fibers POF at jump of index of 1mm of diameter, 0.5 of numeric opening and 1.492 of core index. The source is a diode LED (λ=660 nm, Δλ=40 nm). The ends of the receiving fibers are coupled to two diodes PIN associated to an electronic circuit of treatment of the detected signals. An integrated circuit of multi-function

CI-MPY534 allows to carry out the sum calculations, she/he differs and division of signals. This way the influence of the attenuation of the liquid, Fresnel transmittance and the variations of the intensity of the source of light are eliminated. The complete system of measure is illustrated in the picture of the figure. 2. The distance between emitting fiber and receiving fibers is of 9 and 15 mm respectively. The system was calibrated in the laboratory. Using the geometric pattern of the complete cone that introduces a minimum of error, the calibration curve is drawn. The exit voltage is related to the index of refraction of the liquid. The index of refraction of pure water is used as calibration reference.

With the proposed system and using and constant Temperature (20°C), the indexes of a series of liquid substances were measured. Water with Na-Cl, Sugar, and alcohol were used in the experimental works.

The obtained results are plotted in figures three, four, five and inside the tables I and II respectively.

Figure 2. Sensor head assembly together with the electronic unit.

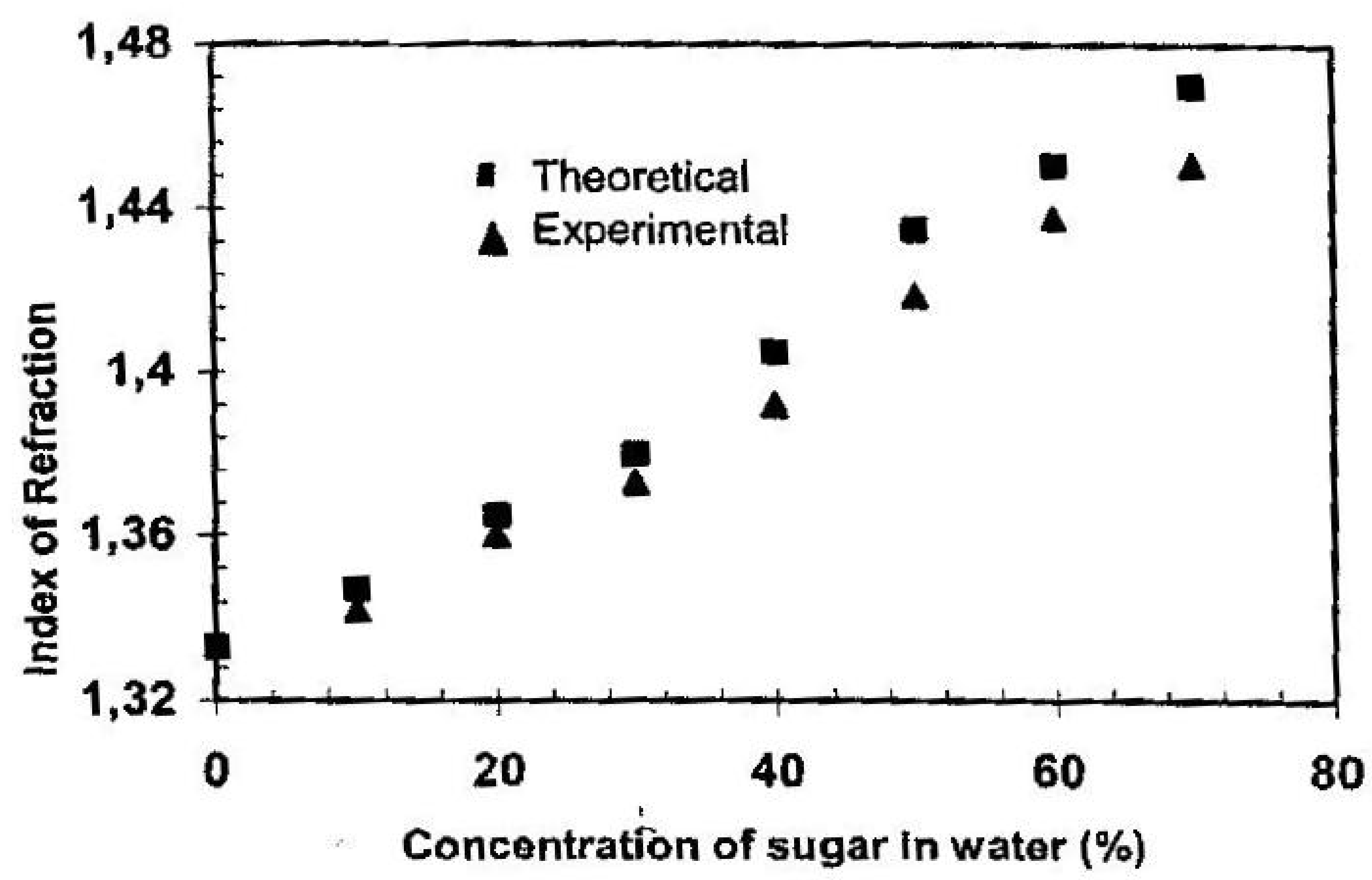

Figure 3. Index of refraction variation for water-sugar concentration.

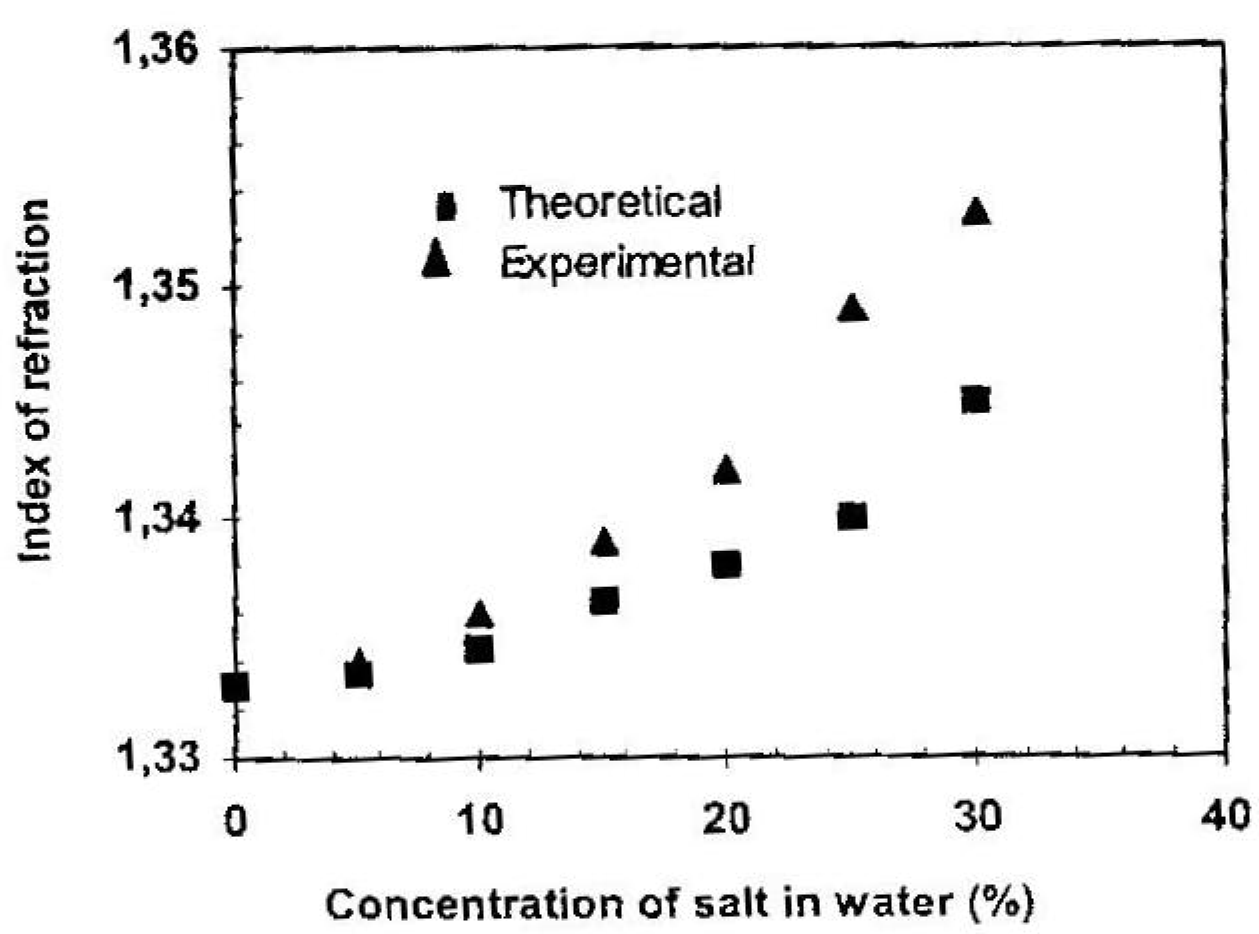

Figure 4. Index of refraction variation for water-salt concentration.

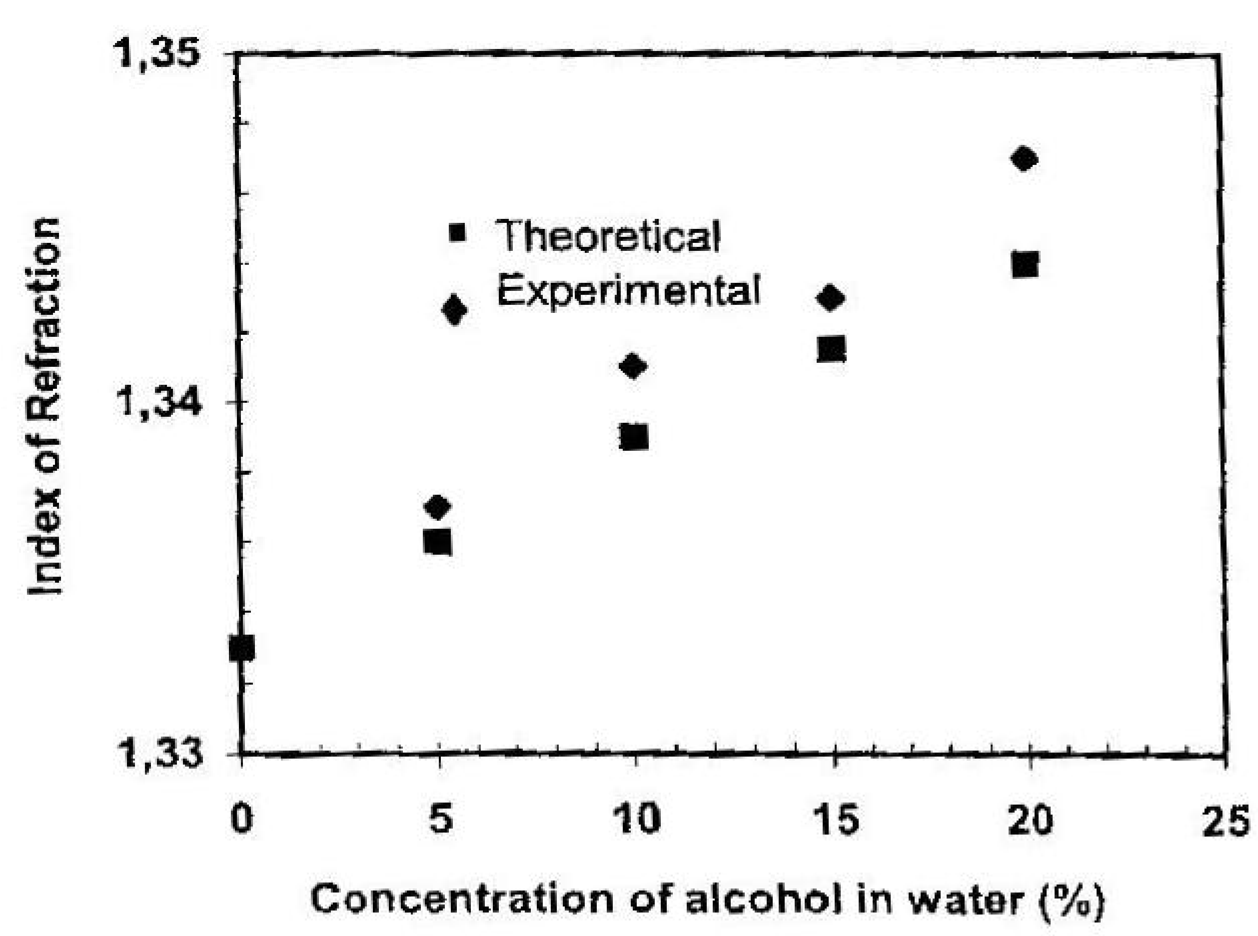

Figure 5. Index of refraction variation for water-alcohol concentration.

Table I. Refractive Index at 20°C of some oil domestic

Type of Oil	Refractive Index
Olive oil	1.466
Corn oil	1.482
Sunflower oil	1.474
Seeds oil	1.490

Table II. Refractive Index at 20°C of different types of beer

% alcohol in the beer	Refractive index
4.8%	1.337
6.6%	1.341
7.9%	1.343

4. CONCLUSIONS

To measure the index of refraction of liquids *in situ* a sensor based on POFs is demonstrated. Due to the differential detection configuration and to the post-processing signal algorithm used, the device is un-sensible to the undesirable intensity fluctuations of the light. The experimental results agree well with the theoretical forecasts and they are acceptable with results obtained by other methods. Finally, it must be mentioned that due to the POF resistance to organic acids and to their flexibility, the proposed system can be used to measure a wide diversity of liquids of industrial interest.

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