Low cost fiber optic sensing of sugar solution

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ABSTRACT

The demand for highly sensitive and reliable sensors to assess the refractive index of liquid get many applications in chemical and biomedical areas. Indeed, the physical parameters such as concentration, pressure and density, etc., can be found using the refractive index of liquid. In contrast to the conventional refractometer for measurement, optical fiber sensor has several advantages like remote sensing, small in size, low cost, immune to EMI etc., In this paper we have discussed determination of refractive index of sugar solution using optical fiber. An intensity modulated low cost plastic fiber optic refractive index sensor has been designed for the study. The sensor is based on principle of change in angle of reflected light caused by refractive index change of the medium surrounding the fiber. The experimental results obtained for the sugar solution of different refractive indices prove that the fiber optic sensor is cable of measuring the refractive indices as well as the concentrations.

Keywords: Refractive index, Optical fiber , sensor and sugar solution

1. INTRODUCTION

Fiber optic sensors are used for the measurement of physical properties such as, refractive index, stress, pressure, and temperature measurements etc. Refractive index is an inherent characteristic of liquid and it is useful to find the physical parameters like concentration, pressure, density etc. of the liquid[1]. Often, refractive index is a measure of purity of a particular substance. In particular, the concentration of solute in the aqueous solution can be determined by knowing the refractive index (RI) of the solution.

Compared to conventional refractometer for measurement of RI of liquid, optical fiber RI sensor has several advantages like remote sensing, small in size, immune to EMI etc.,[2,3]. Many types of fiber optic sensors are used to measure the refractive index of the liquid.

J Villatoro et al[4] developed a refractive index sensor based on the radiation losses introduced by the sample medium in a cladded multimode tapered fibre. P. Nath et al[5] presented a sensor based on frustrated total internal reflection effect caused by refractive index change of a medium surrounding an optical fiber tip. Joel Villatoro et al[6] reported a sensor owing to the core diameter mismatch. Iadicicco et al. used etched fiber Bragg grating[7], long period grating[8] for the measurement of RI. Meriaudeau et al[9] presented a fiber optic refractive index sensor based on gold island surface plasmon excitation. Lo et al[10] developed a optical fiber refractometer based on phase modulation using path-matching differential interferometries (PMDI) with two parallel Fabry-Perots sensing cavities.

Suhadolnik et al[11] presented a theoretical model of intensity based optical fiber refractometer. Measurement of refractive index of liquid using fiber optic displacement sensor was demonstrated by A.D.Shaligram and Chaudhari et al[12] Majority of the fiber optic RI sensors need elaborate and precision arrangements and hence there is a need to develop a simple, low cost and easy arrangement to measure the RI of liquid. The development of sensing devices for fast and reliable monitoring of sugar or sweetness in solutions is very important in food and juice industries, and in wine manufacturing[13]**.**

In this paper we have discussed a simple low cost fiber for the measurement of refractive index of sugar solutions of different concentrations.

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2. WORKING PRINCIPLE

The sensor setup consists of two multimode fibers with a step index profile, where one is transmitting fiber and the other is receiving fiber. The light from the source is launched into the transmitting fiber and on emergence reflected by the reflector. The incident light on the reflector forms a cone of emittance from transmitting fiber. The reflected light is received by the receiving fiber. The reflected light intensity is sensed by a photo-detector to be displayed as output power in volts.

The transmitting and receiving fibers are parallel to each other and are at a distance of 'x' from the reflector. The space between the fiber and reflector is filled with liquid of refractive index 'n_0'. Then the cone angle 'θ_1' is

$$\theta_1 = \sin^{-1}\left(\frac{NA}{n_1}\right)$$

Here NA is numerical aperture of the transmitting fiber. If 'x' is the distance of the sensor tip and the reflector, then the radius 'r_1' of the reflected cone at a distance '2x' is given by[11]

$$r_1 = a + (2x)\tan(\theta_1)$$

Here 'a' is the radius of the transmitting fiber. Light collected by the receiving fiber is determined by the overlap region of the acceptance cone of receiving fiber and that of transmitting fiber. If the medium between the reflector and the sensor tip is filled with liquid of refractive index n_2, such that $n_2 > n_1$ then $\theta_2 < \theta_1$ and $r_2 < r_1$ and hence the area of the overlapping region decreases. The output power decreases with reduction in the spacing between the reflector and fiber tip. As the value of 'x' becomes higher, entire region of the receiving fiber tip is covered by the reflected beam and there is no change in the overlap area, then the fall in output power follows the inverse square law. The reflected beam becomes narrower with the increase in refractive index and hence more light is concentrated in the beam. Thus the output power corresponding to a specific distance 'x' increases with refractive index[1]. Therefore maintaining the distance between the reflector and the probe at a certain value of x, the received light intensity serves as a measure of refractive index of liquid as well as the concentration of the liquid.

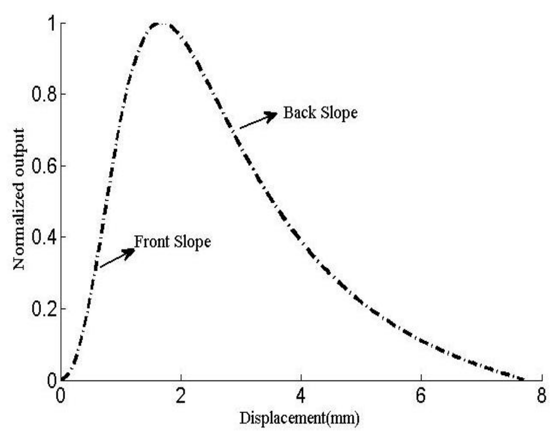

Fig.1. Characteristic curve of proximity sensor

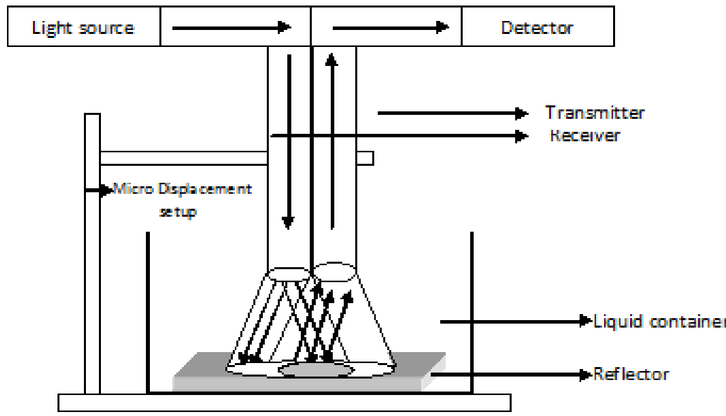

Fig.2. Schematic diagram of experimental setup

3. EXPERIMENT

The sensor setup consists of plastic optical fibers as transmitter and receiver, a light emitting diode (640 nm), a photo diode (IF-D93 extends from 400 to 1100 nm), Transimpendence amplifier, Micrometer and a Voltmeter to measure the output voltage. Fig.2 shows the block diagram of the plastic optical fiber sensor and Fig.3 is fiber sensor used in this study. Two 60 cm length PMMA (polymethyl methacrylate) fibers of core/cladding diameter 980/1000 µm and refractive indices 1.492 and 1.402 are used. The two fibers are aligned parallel to each other and glued together up to 5cm at the end of the fibers with cynoacryolate epoxy. An aluminum coated mirror is used as reflector and it is fixed at the bottom of the container. A micro displacement meter is used for displacing the probe from the reflector in successive steps of 0.5 mm. The intensity of reflected light is measured in terms of millivolt against the corresponding displacement. The reflected light intensity is measured using deionized water by changing the position of the fiber probe with respect to the reflector. The sample sugar solutions of different concentrations (measured in percentage by mass) were prepared by dissolving sugar in deionized water. We have used cane sugar and the refractive index of sample solutions were determined by spectrometer method using hollow prism. Fiber sensor measurements were carried out for sugar solutions of different concentrations at room temperature.

Table.1 Increase of refractive index with the concentrations of sugar solution

Sugar concentration (%)	**Refractive Index**
0	1.336
10	1.349
20	1.362
30	1.379
40	1.395
50	1.419

4. RESULT

The reflected light intensity was measured in terms of output voltage. The variations of output voltage with displacements for various concentrations of sugar solutions are shown in Fig.5. The output voltage increases with the displacement and it is maximum at a value of ‘x’ , then decreasing with the increasing value of ‘x’. Further as the concentration is increasing, the peak voltage is also increasing. This is due to the increase of refractive index with the concentrations of the sugar solution. The variation of peak voltage with the concentration and with the refractive index of the sample solutions are shown in Fig. The intensity based refractive index and the concentrations are strongly dependent on distance characteristics which are the essential problem of the method. Eventhough, there is an optimized insensitive region of the displacement characteristics for which resolution of refractive index as well as concentration measurements are high enough to differentiate various solutions[1].

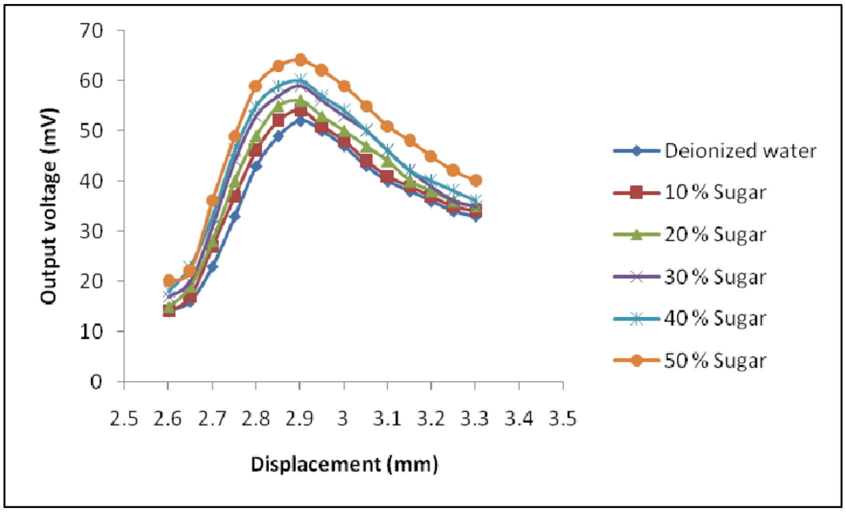

Fig.3. Variation of Light output with displacement for different concentrations of sugar solutions

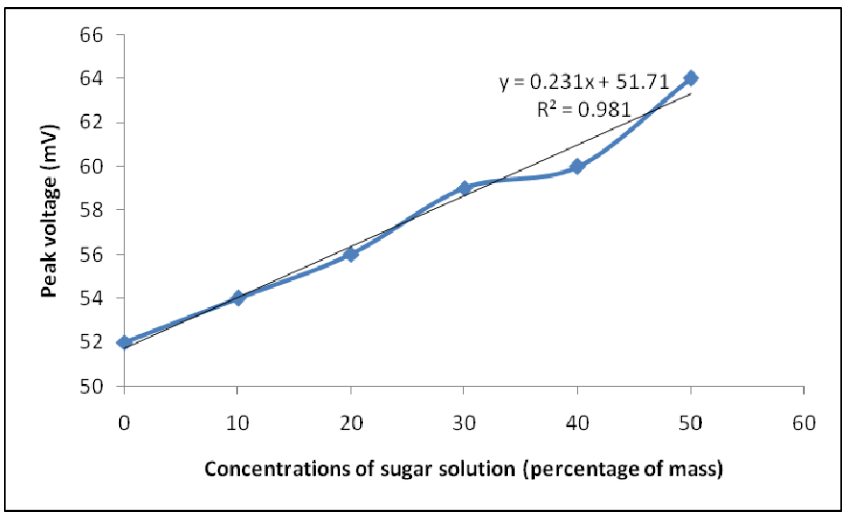

Fig.4. Variation of peak voltage with different concentrations of sugar solution

The correlation between the light intensity and refractive index is shown in Fig.6. Fig. 8 shows the correlations between the light intensity and the concentrations. The correlation coefficient R^2, are 0.981 and 0.990 for the variations. Measurement of refractive index and concentrations of a liquid can be done with the help of characteristic curve drawn with known values of RI and concentrations. The response of the sensor depends on characteristics of the fiber used, source and detector.

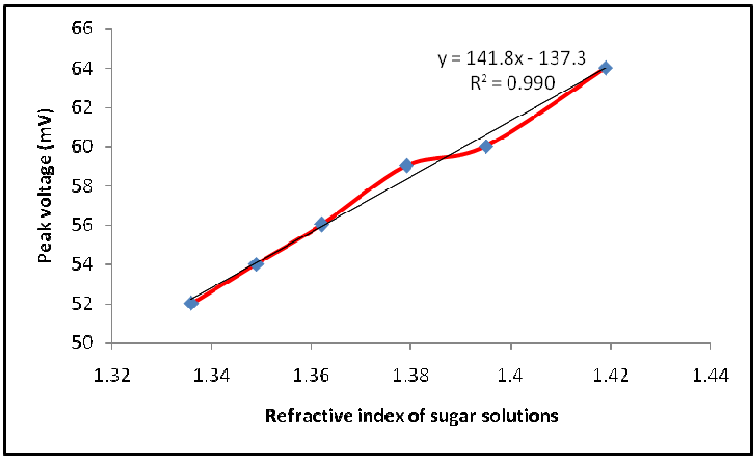

Fig.5. Variation of peak voltage with refractive index of sugar solution

5. CONCLUSION

This paper has reported a novel low-cost optical fiber sensing system for sugar content determination in sugar solutions and the refractive index of sugar solutions. The results obtained can be useful for the development of an instrument for online measurement of refractive index and concentrations of the liquid. This type of sensor is useful to find the sweetness of solutions in food and manufacturing industries. The simple design of the sensor has excellent repeatability.

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