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Implementation of U-Shaped Probe in the Construction of a Fiber Optic Sensor to Determine the Refractive Index of Liquids in the dynamic Range of 30^0C to 60^0C

Dr. S. Venkateswara Rao
Department of Physics, JNTUH College of Engineering Hyderabad, Telangana, India - 500085

Abstract— The whole nature of most of the substances is determined by the study of measurement of especially the refractive index, which decides their applicability and utility in different fields at various occasions. A uniform U-shaped glass probe of very fine dimension is shown to sense the refractive index of a liquid in which the U-shaped glass rod is immersed at various temperatures. In the present paper, the refractive index of liquids such as methanol mixed in benzene and propanol mixed in benzene was studied over a wide range of temperatures ranging between 30^0C to 60^0C using a U-shaped glass sensing probe. With increase in the temperature of the active medium surrounding the glass probe, the slope of the sensor response is found to be dramatically increased in terms of light reception. The U-shaped glass rod is sensitive to the presence of absorption at the wavelengths at which the refractive index is being measured and to the chemical nature of the solute. The output power variations in the intensity of the light with changes in the temperature ranging between 30^0C to 60^0C have been recorded. The sensor so developed can be used to determine the refractive index of liquids either transparent or dark whose refractive index values lie between $1.33n_D$ and$1.50n_D$ and the dynamic range of temperatures between 30^0C to 60^0C at the wavelength of 633nm.

Keywords* — *Sensing Probe; Intensity Variation; Range of Temperatures; Dynamic Range; U-Shaped Probe.

1. Introduction

Various fiber optic sensors have been proposed for the measurement of physical and chemical parameters, as the fiber optic sensors offer numerous advantages over the conventional sensors [1, 2]. Using other methods, only a few reports have been appeared on the systemic measurement of refractive index of liquids at various temperatures [3]. The immunity to electromagnetic interference and radio frequency interference, small size, remote sensing, possibility of multiplexing information from a large number of sensors in a single fiber, explosion proof and cost effectiveness are some of the advantages of the optical fiber sensors. In most of the sensors, there is a need to measure small refractive index changes in small volumes of liquid especially in biosensors.

The need for the refractive index sensors have greatly increased because of its application in quality control of food products, a wide range of other industries like pharmaceuticals, beverages, flavors, fragrances, petrochemicals and as well as for technical and medical applications. For the measurement of temperature of liquids, few methods have also been used as reported in the literature [4]. In the experiments designed to sense refractive index, optical fibers have been used as vehicle for carrying light, but not directly as a sensor of RI [5, 6]. In the context of its use as a sensor, a few reports refer to the significance of the cladding of a fiber was reported in the literature [7, 9]. In this paper, we describe experimental results on refractive index sensing by a low cost plastic cladded silica fiber for carrying the light from one end to the other end. The investigation was taken up on the influence of light absorption by solute and that of its chemical nature on refractive index measurement with reference to the power reception at the output end of the sensor.

2. Materials and Methods

The general configuration of the fiber optic sensor system consists of a transmitter at the input end comprising of a light source of wavelength of interest and light detector at the output end, both are connected by a PCS fiber in between. In general the range of light that can be used in the optical fiber sensor is between 400nm to 1500nm depending on the parameter to be measured and the design of the sensor. This is because when light travels through glass medium suffers heavy loss due to its interaction with the glass material in case of silica fibers and plastic material in case of plastic fibers. The loss of light due to material interaction depends primarily on the wavelength of the light used as source within the usable range i.e. between 400nm to 1500nm. A semiconductor light source of 633nm was used in the experiment as it offers the lowest material loss of light procured from the local suppliers in the market made by Hi-Q electrons. Three kinds of optical fibers can be used as light transmitting medium in between the light source and the light detector.

- Glass (silica) core with glass (silica) cladding
- Plastic (polystyrene) core with plastic (Teflon) cladding

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- Glass (silica) core with Plastic (Teflon) cladding

For the purpose of the present experiment a PCS (Plastic Clad Silica) Multimode fiber has been employed in order to avoid the mismatch between the dimensions of the glass rod used and the transmitting fiber. These fiber supplied by optiwave technologies are used as the light transmitting medium. The employment of single mode fibers can be ruled out in the present experiment due handling difficulties arises out of their small size and due to the brittleness of the small diameter glass rod.
Sodium borosilicate U – shaped glass rods have been brought from the glass blower working in the glass plant in the local market. The length between two prongs is selected to 5 cm and the thickness of the glass rod is chosen as 0.5 mm in diameter in order to avoid the mismatch between the glass rod and the fiber with outer plastic jacket removed.

In the present work three types of volatile liquid chemical are used, 1 benzene, 2 methanol, 3 propanol. The ultra high pure chemicals are used in the experiment as liquid cladding to the U-shaped glass rod with a view to obtain the accuracy in the final results of the study,which as a analyte in the region of sensing of the sensor system. The routinely available glass burettes as the glass is immune to chemicals are used in the setup. A bench mark power meter is employed to record the power outputs at the receiver end of the setup. The measurement of refractive indices of all the mixtures Abbes' refractometer was implemented. The light source to the glass rod and glass rod in turn to the receiver are connected using SMA connectors.

3. Results

The experiment was carried out using three separate arrangements.

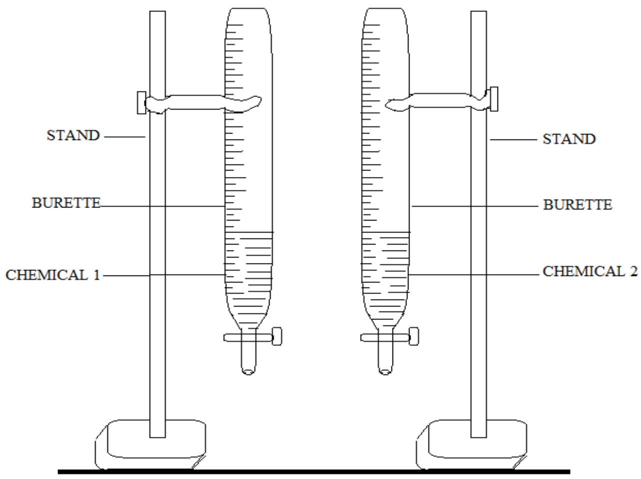

Fig. 1: Two burette system

- Two burette system, for the measurement of liquid mixtures with the combination of benzene and methanol, and benzene with propanol in different proportions [fig. 1].
- Abbe's refractometer to measure the refractive indices of all the mixtures prepared using burette system [fig. 2]
- Sensing system consists of three basic components [fig. 3]
  a. 630nm light source
  b. Light detector (bench mark optical power meter
  c. Sensing zone consists of a U-shaped glass probe of specific dimensions with temperature bath

Fig. 2: Abbes' Refractometer

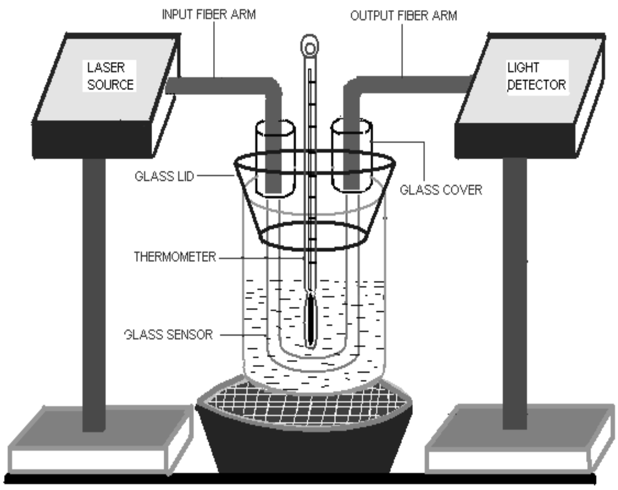

Fig. 3: Sensing System

The experiment was started initially using the two burette system [Fig. 1]. The ultra pure benzene and methanol are taken separately into the burette 1 and burette 2 respectively. Then both the chemicals are taken in different proportions into air tight glass bottles, thus

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preparing the mixtures of two liquids and kept them ready for the experimentation.

In the second part of the experiment the refractive indices of all the liquid mixture were determined with the help of Abbes' refractometer [Fig. 2] at the temperature range of 30^0 Cto 60^0C in steps of 5^0C each and the values are recorded and tabulated.

Experimental setup of sensing system [Fig. 3] was employed for measurement of liquid refractive index as the final part of the experimentation. The experimental setup was arranged by connecting the two ends of the U-shaped probe to a PCS fibe of 25cm in length. The joints between the glass rod and the fibers were properly glued with index matching liquid and then covered tightly with adhesives. The input fiber arm is connected to a light source of 633nm, and the output fiber arm is connected to a power meter.

The arrangement so formed is immersed in a beaker containing benzene and methanol mixture. Taking initially 10ml of methanol and subsequently removing 1 ml of methanol and adding equal amount of benzene into the beaker, maintaining the total volume 10ml, the set up can be kept ready each time.

Immersing the U-shaped glass probe of 5cm prong length and 0.5 cm in diameter into the first liquid mixture and simultaneously heating the liquid bellow the boiling point, light was launched from the source and the light reaching the output power meter was observed. The observations are noted and tabulated. This method was repeated by immersing the U-shaped glass probe into other liquid mixtures and simultaneously heating the mixtures from 30^0 C to 60^0C in steps of 5^0C each.

Table 1: Refractive index obtained from Power data at various temperatures of the Benzene and Methanol (Free space power output: -45.0dBm) for 0.5 mm dia U shaped glass rod

C_6H_6 + CH_3OH	30°C		35°C		40°C		45°C		50°C		55°C	
	dBm	R. I.	dBm	R. I.	dBm	R. I.	dBm	R. I.	dBm	R. I.	dBm	R. I.
0+10	-46.4	1.325	-46.1	1.298	-45.6	1.277	-45.2	1.260	-44.7	1.239	-44.4	1.227
1+9	-47.0	1.338	-46.4	1.325	-46.1	1.298	-45.6	1.277	-45.2	1.260	-44.7	1.239
2+8	-47.4	1.352	-47.0	1.338	-46.4	1.325	-46.1	1.298	-45.6	1.277	-45.2	1.260
3+7	-47.8	1.369	-47.4	1.352	-47.0	1.338	-46.4	1.325	-46.1	1.298	-45.6	1.277
4+6	-48.2	1.388	-47.8	1.369	-47.4	1.352	-47.0	1.338	-46.4	1.325	-46.1	1.298
5+5	-48.7	1.404	-48.2	1.388	-47.8	1.369	-47.4	1.352	-47.0	1.338	-46.4	1.325
6+4	-49.0	1.420	-48.7	1.404	-48.2	1.388	-47.8	1.369	-47.4	1.352	-47.0	1.338
7+3	-49.4	1.436	-49.0	1.420	-48.7	1.404	-48.2	1.388	-47.8	1.369	-47.4	1.352
8+2	-49.7	1.452	-49.4	1.436	-49.0	1.420	-48.7	1.404	-48.2	1.388	-47.8	1.369
9+1	-50.2	1.470	-49.7	1.452	-49.4	1.436	-49.0	1.420	-48.7	1.404	-48.2	1.388
10+0	-50.5	1.487	-50.2	1.470	-49.7	1.452	-49.4	1.436	-49.0	1.420	-48.7	1.404

The entire data obtained experimentally viz. proportions of liquid mixtures, refractive indices of all mixtures at different temperatures, and finally the powers reaching into the output detector at various temperatures were tabulated [Table. 1].

Thus by using this standard curve with a standard relation between output power and the refractive index, the refractive index values are determined simply for each and every power value for each and every mixture, and tabulated and represented in the form of graphs in Fig. 5.

The experiment is again carried out in the same manner by repeating with another binary mixture benzene and propanol to observe the trend and the corresponding graphs are drawn in Fig. 6

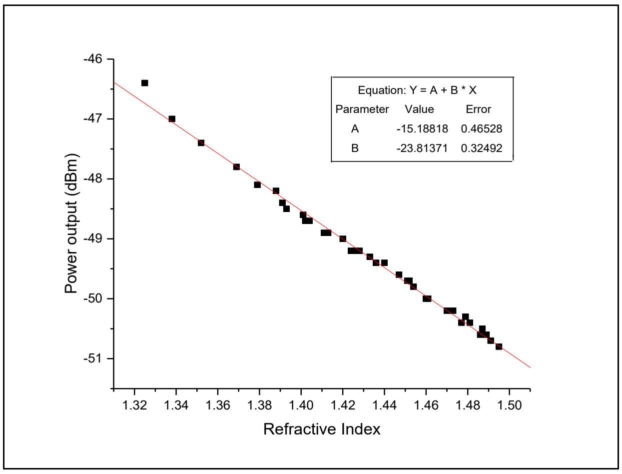

Fig. 4: Standard graph for benzene and methanol at 30°C

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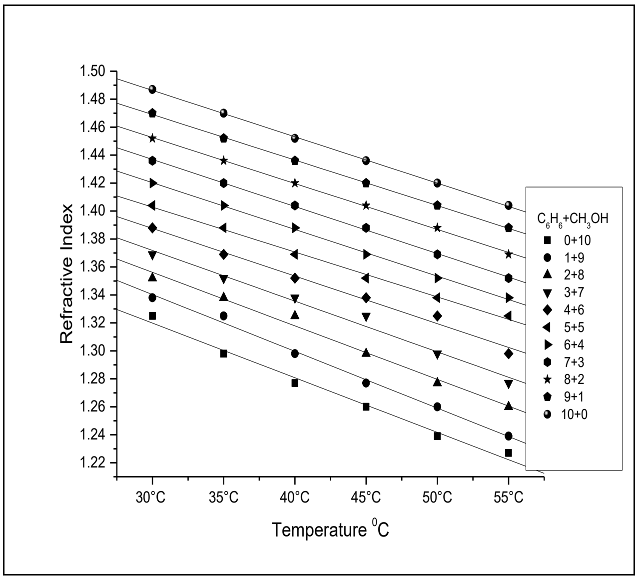

Fig.5: Refractive index at various temperatures for methanol and benzene mixture

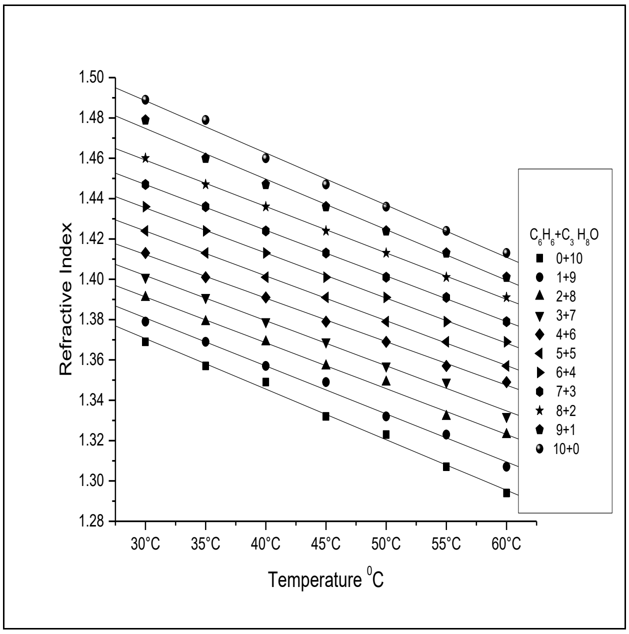

Fig.6: Refractive index at various temperatures for propanol and benzene mixture

4. Discussion

It can be concluded from the graphs plotted, that the refractive index of any unknown liquid can be determined using the standard graph drawn between output power and refractive index at room temperature whose RI values lie between1.3 to 1.5 just by simply exposing the liquid to the sensor in the beaker at various temperatures ranging from 30^0 C to 60^0 C.

Calibration: In any sensor or detector calibration is very crucial aspect in the design, construction and application point of view. Calibration is nothing but the forming a relationship between the change in the measurer parameter corresponding to a change in the measurand parameter apart from other requirement like ease with which the parameter can be measured, size of the device, distance from which it can be measured, limits of temperatures within which it measures, longevity, reliability, interference of other parameters on the measured we measure i.e. immune to other parameters, flexibility of multiplexing, cost effectiveness etc.

In the present study, initially the calibration is done by forming a relation between the chemical mixture (Benzene+Methanol - measurand) and the light (measurer) that is transmitting from light source at the input end to the light detector at the output end via the sensing zone (U-shaped glass rod cladded with chemical mixture at room temperature. For this purpose liquids with different concentrations having a range refractive index values have been prepared taking various proportions (10ml+0ml), (9ml+1ml), (8ml+2ml), (7ml+3ml), (6ml+4ml), (5ml+5ml), 4ml+6ml), (3ml+7ml), (2ml+8ml), (1ml+9ml), (0ml+10ml) of mixtures benzene and methanol respectively making the total volume equal to 10 ml using the two burette arrangement. Each mixture with different volumes having a specific value of mole fraction, having a specific value of refractive index, and a specific value of concentration, thus all mixtures provide a set of liquids having refractive index values ranging from $1.33n_D$ to $1.5n_D$. This technique was used with a view to enhance the capability of the sensor to measure all the liquids whose refractive index lies in the range between $1.33n_D$ to $1.5n_D$ either the liquid is transparent or dark.

In the next step the functioning of the sensor is extended to measure the liquid refractive index at various temperatures below the ranges of the boiling points of the mixtures prepared. For this purpose a heating bath is used where the mixtures are heated in a special glass container having ground nut oil, whose boiling point is around 350^0 C. The chemical mixtures in the glass containers are heated by an indirect method by dipping the mixture containing glass beaker into the heating ground nut oil container. The by launching the light from the source and heating the chemical mixtures, the power reaching the detector was noted down. Then with the help of the Abbes' refractometer the refractive indices at different temperatures are determined.

Now the sensor is calibrated to measure the refractive index of any liquid in above mentioned temperature range and above mentioned dynamic r. i. range by plotting a graph between output power and refractive index at different temperatures. This procedure is carried out by

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repeating the experiment using another set of two liquids benzene and propanol with a view to confirm the working capabilities of the FO sensor. The similar trend was observed as with the results of the benzene mixed methanol yielding accurate values on par with that reported in the standard literature.

5. Conclusion

In the present study, a novel design and technique of a fiber optic U-shaped glass refractometer has been proposed for the determination of refractive index at various temperatures in the temperature range between 30^0 C and 60^0 C and in the dynamic range of $1.33n_D$ to $1.5n_D$. The data for the power output with respect to the varied temperature and according changes in the refractive index have been collected and has been shown in table 1. The calibrated curve between the output power and refractive index at 30^0C (room temperature) can be used to determine the refractive index of any unknown liquid either transparent or dark, just by dipping the U-shaped probe into the liquid and reading the output power and verifying the corresponding refractive index value on the X-axis of the graph. The results conclude that the power output decreases when the refractive index of the liquid increases. Thus the calibrated standard graph works like a meter to read the refractive index of the unknown liquids in the above said range at room temperature.

In the second phase of the experiment, the sensor is studied to measure the refractive index values of liquids at other than room temperature by rising liquid temperatures to below their boiling point and the data (Table 1) is plotted graphically in the second graph (fig. 5). In this case, if temperature of the liquid increases, the refractive index of the liquid decreases and accordingly the output power in the detector increases. Thus at higher temperatures the refractive indices of liquids decreases obeying the natural physical principles.

For further confirmation, this technique has been cross checked with the help of two liquid mixtures i. e. benzene mixed in propanol and benzene mixed in methanol which maintained the similar trend as explained above in case of methanol mixed in benzene. The conventional methods which run into difficulty in many occasions can be replaced with the novel method proposed in the present study. The present method offers many advantages in measuring the refractive index of liquids at various temperatures.

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