STUDY OF TEMPERATURE AND CONCENTRATION DEPENDENCE OF REFRACTIVE INDEX OF LIQUIDS USING A NOVEL TECHNIQUE

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ABSTRACT
A simple and reliable method of measuring the refractive index of liquids is reported in the present paper. The technique was employed to study the temperature dependence of refractive index of water (at sodium D-line 589nm). By measuring the refractive index of water at different temperatures, the temperature coefficient of refractive index (*dn/dT*) was determined. In addition to this, refractive index of different solutions as a function of the concentration was studied. The results were compared with the results obtained from commercial refractometers and it was found that this technique is quite reliable and can be safely used in the study of the optical properties of any transparent liquids

INTRODUCTION
Refractive index is one of the most important optical properties of a medium. It plays vital role in many areas of material science with special reference to thin film technology and fiber optics. Similarly, measurement of refractive index is widely used in analytical chemistry to determine the concentration of solutions. Recent studies [Schwartz 1999, Olesberg 2000, Shlichta 1986] provide more detailed discussion on the concentration mapping by the measurement of refractive index of liquids. Temperature coefficient of refractive index can also be used to calculate thermal expansion coefficient [Miller 1975]. Several techniques are reported in literature for the measurement of concentration and temperature dependence of refractive index of liquids [McPherson 1999, Garcia 1999, Otalora 1999, Miyashita 1994]. The present paper reports a relatively simple and effective technique, which can be used to measure the refractive index of the liquid at different temperatures.

The absolute refractive index of a medium is the ratio of the speed of electromagnetic radiation in free space to the speed of the radiation in that medium. The relative refractive index is the ratio of the speed of light in one medium to that in the adjacent medium. Refraction occurs with all types of waves but is most familiar with light waves. The refractive index of a medium differs with frequency. This effect, known as dispersion, lets a prism divide white light into its constituent spectral colors. For a given color, the refractive index of a medium depends on the density of the medium, which on the other hand is a function of temperature. By measuring the refractive indices at different temperatures, the temperature coefficient of refractive index (dn/dT) can be determined.

MATERIAL AND METHOD
A convenient formula for refractive index, n, can be obtained in the minimum deviation case when a ray of light suffers deviation while passing through a prism. The deviation produced by the prism depends on the angle of incidence. For a certain value of the angle of incidence, the angle of deviation is minimum. If D_m denotes the angle of minimum

deviation for a given prism of refractive angle A, then the refractive index of the material of the prism n is given by,

$$n = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} \quad .... \quad (1)$$

Equation (1) has been employed to calculate the refractive index of the liquids.
Experimental arrangement used in our study is depicted in Fig. 1. Specially constructed hollow prism was used to measure the refractive index of liquids with the help of an optical spectrometer. A monochromatic source of light (sodium lamp) was used and a collimated beam was allowed to fall on one reflecting face of the liquid prism and the angle of minimum deviation was determined for yellow light (at sodium Dline 589 nm). Mean of two values were taken for each angle of minimum deviation. For the measurement of refractive index at different temperature, the liquid was heated up to 80°C and poured into the hollow prism and the angle of minimum deviation was measured at different temperatures of the cooling liquid. A thermometer was inserted in the liquid avoiding the path of light being observed.

To study the variation of refractive index of salt solutions as a function of concentration, an electronic balance weighed salts and solutions of required concentrations were prepared by dissolving the salts in 100 ml of water. Thus prepared solutions were filtered before pouring into the hollow prism. The hollow prism was rinsed carefully after every measurement. Solutions of lower concentrations (20%, 10%, 5%, 2.5% and 1.25%) were made by diluting the solutions with equal volume of water.

RESULTS AND DISCUSSION

Effect of Temperature on Refractive Index of Water

The refractive index of water as a function of temperature is depicted in Fig 2. The result shows a linear dependence of refractive index of water on temperature in the range 30°C-70°C. By applying data analysis program the experimental data were subjected to curve fitting and the temperature coefficient of refractive index of water was found to be equal to -1.853×10^{-4}/C. For highly accurate measurements, the optical constants of the glass container should also be taken in account because the light will pass through both the solution and the container. According to the literature [Lukin 1993], the temperature coefficient of refractive index of glass is of the order of 10^{-4}/C. It is evident that very small error can occur if the temperature dependence of the refractive index of glass is not taken into account while measuring the temperature coefficient of refractive index of liquids.

Effect of Concentration

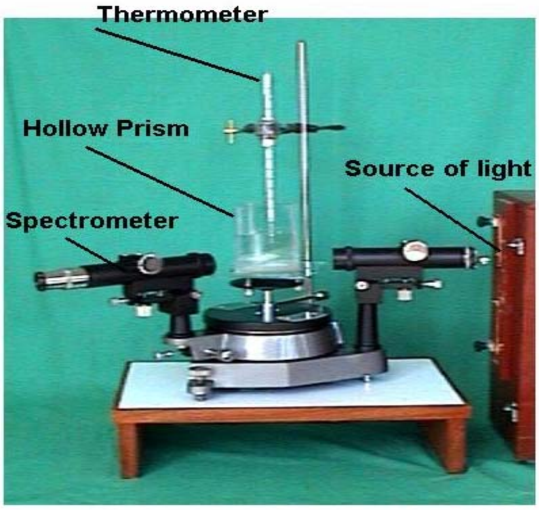

Fig.1 Experimental set-up for the measurement of refractive index by an optical spectrometer.

Refractive index of common salt solution as a function of concentration is depicted in Fig. 3. For 20% solution, refractive index is as high as 1.358, which reduces to 1.331 when the solution is diluted to a concentration of 1.25%. With the decrease in concentration, the density of the solution also decreases resulting a decrease in refractive index. The results showed that the refractive index of the solution of concentration less than 2.5% measures nearly the same as that of the pure water. The result indicated that the effect of concentration on refractive index is dominant up to the concentration of 5%.

After that there is weak dependence of concentration of refractive index. Fig. 4 shows a similar result for sugar solution. As the solubility of sugar is high, the measurements were performed up to 40% concentration of the solution. The refractive index of the sugar solution was found to be 1.387 for 40% solution. The value reduces to 1.332 when the concentration was reduced to 2.5%. In contrast to the result of salt solution, the effect of concentration is strong up to 20% concentration of the sugar solution. However, after this value the dependence becomes weak.

Fig 5, 6 and 7 depict the dependence of refractive index of propanol_1, sucrose and potassium chloride solution on their concentration respectively. A comparison is made between the results obtained from our measurement and the values mentioned in literature [http://www.mt.com]. It is evident that our results are in agreement with the literature value so far as the nature of variation is concerned. Repeating the experiment checked the value of refractive index of propanol_1 solution of 20% concentration with higher deviation. Similarly, refractive index of sucrose solution of concentration 10% was measured twice (indicated by error bar). In the same way for potassium chloride, the experiment corresponding to 10% and 20% concentrations were repeated.

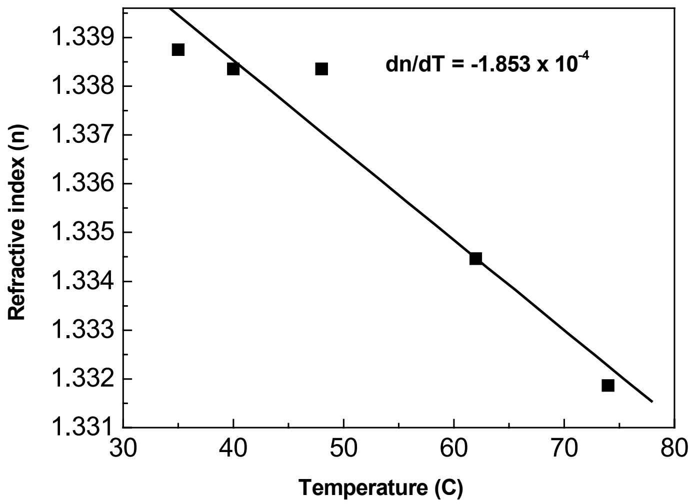

Fig 2 Temperature dependence of refractive index of water.

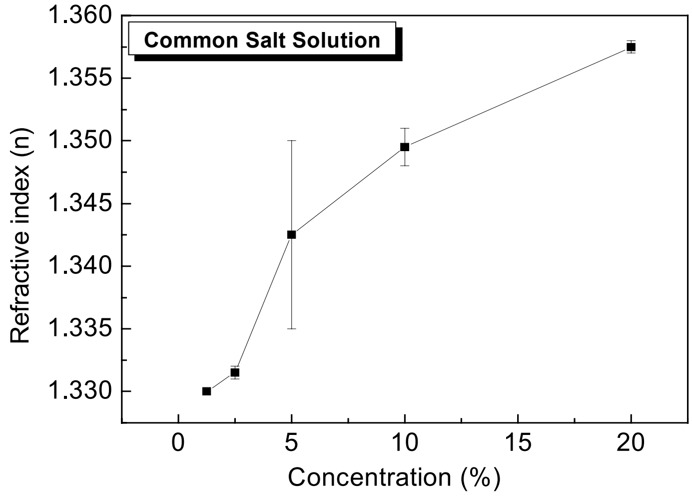

Fig. 3 Refractive index of sodium chloride solution as a function of its concentration expressed in percentage.

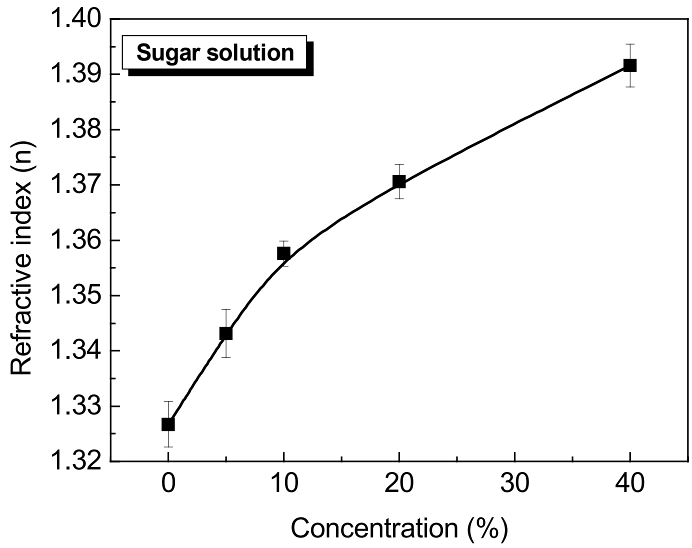

Fig. 4 Refractive index of sugar solution as a function of its concentration expressed in percentage.

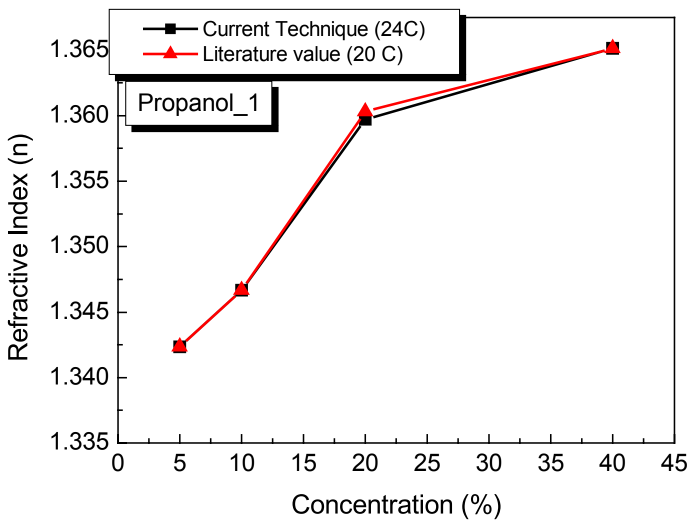

Fig. 5 Refractive index of Propanol_1 as a function of concentration measured by the present technique and obtained from literature.

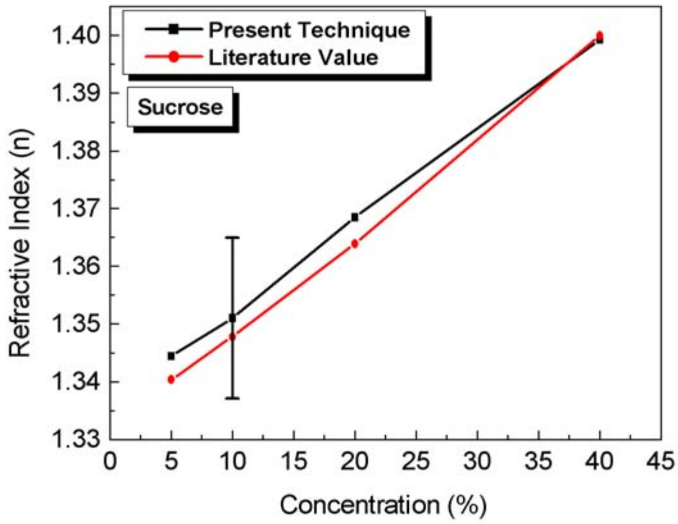

Fig. 6 Refractive index of sucrose as a function of concentration measured by the present technique and obtained from literature.

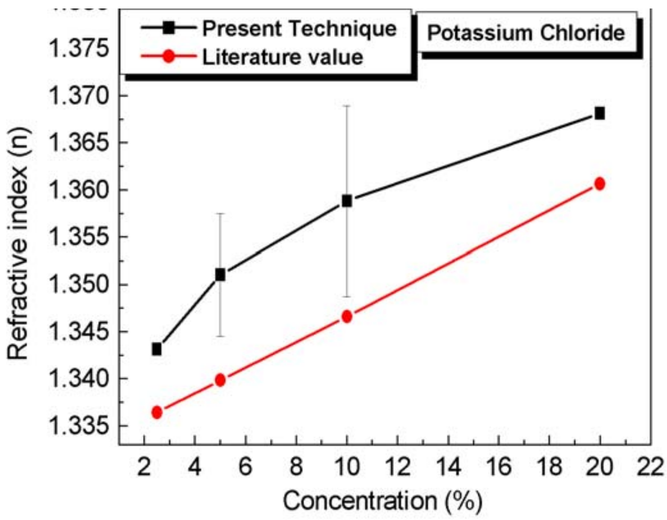

Fig. 7 Refractive index of potassium chloride as a function of Concentration measured by the present technique and obtained from literature.

CONCLUSION

We have been able to design a hollow prism suitable for the measurement of refractive index of transparent liquids. Experimental results showed that this technique could be safely employed to study the dependence of refractive index of solutions on their concentration as well as on the temperature. The temperature coefficient of refractive index of water (in the range of 30-70°C) was determined and it was found that the value is in agreement with the results obtained from other methods of measurement. A linear dependence of refractive index of some solutions (common salt, sugar, propanol_1, sucrose, potassium chloride) with their concentration was observed.

ACKNOWLEDGEMENT
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