Nat. Volatiles & Essent. Oils, 2021; 8(4): 5537-5551

Dynamic Range Specific Temperature Dependent Uniform U-Shaped Glass Rodbased Opticalfiber Refractometer Operating At 660nm

S. Srinivasulu[1*] & Dr. S. Venkateswara Rao[2]

[1&2]Department of Physics, College of Engineering Hyderabad, J N T University Hyderabad, Hyderabad, Telangana State, India.

Email: S. Srinivasulu (siluverusrinivasulu@gmail.com)

ABSTRACT: Wide range of sensors are in use to determine the refractive index of various liquids across the world using electronic, mechanical, optical and magnetic mechanisms. In the present paper, a simple miniaturized optical fiber sensor based on a U-shaped glass rod as a sensing element to study the refractive index of various liquids either dark or transparent in the temperature range of 10^{o}C to 60^{o}C using a combination of binary liquids of Benzene and tert-Butanolhas been described. The sensor is designed by connecting the optical laser source of 660nm and an optical detector of benchmark make using two plastic-clad silica fibers of equal dimensions of 200/230µm creating a sensing zone by jointing U-shaped glass rod of specific dimensions at the middle of the two fibers. Immersing the glass rod into the binary mixture the light injected from the source is observed at the detector end and forming the relationship between the concentration of liquid mixtures at various temperatures and output power reaching the detector, a calibrated curve has been plotted, which can be used to determine the refractive index of liquids in the range of 1.36312n_D to 1.51215n_D.

Keywords: Benzene, Calibrated curve, Laser source of 660nm, Refractive index, tert-Butanol, U-shaped glass rod

INTRODUCTION

Refractive index study of liquids is required to be undertaken in a wide range of fields and industries such as beverages, pharmaceuticals, food productions, chemicals, fragrant, medical and other important areas in day-to-day life. Several methods are in use in the determination of the refractive index of liquids at various temperatures. The properties of liquids and their behaviors can be determined mainly with the help of studying a single characteristic parameter i.e. refractive index. The present sensor which uses optical fibers as the conduit of the transmission of light, offers many advantages compared with the mechanical, electronic, and magnetic, etc., sensors.

The first optical fiber which works based on the guidance of light was developed by K.C.Kao and Hock Ham in the year 1966 was revolutionized the telecommunication industry initially. But in the beginning,the losses offered by the optical fibers are incomparable to the copper communication systems which are already in use by then. The struggle of the scientific community during the 1970s to reduce the losses in optical fiber led to the development of fiber optic sensing systems and devices [1-5]. The inherent characteristics of optical fibers i.e. enhanced sensitivity over the existing sensors; construction versatility and remarkable compatibility with optical fiber technology in telecommunications make them superior in major sensing applications [6-9]. Sensors based on optical fibers are of low cost due to the abundant availability of raw material, their robustness, small size, flexibility in handling, the ability of remote monitoring, multiplexing make them efficient solutions in several industrial applications [10-16]. The other advantages of optical fiber sensors make them be implemented in unfavorable environmental situations such as high voltages, noise, fields with strong electromagnets, in an explosive environment, presence of nuclear radiation fields, chemically corrosive environments, and even at greater temperature values among others [17-21]. The selection of material for the cladding and core imposes certain restrictions in the development of fiber optic sensing technology [22-27]. The other limitations of use of fiber optic sensors are the inherent losses; non-linearity, birefringence and dispersion are among others in the progress of their applications in various sectors [28, 29]. The fiber optic photonic crystal sensors which were introduced in 1996 offered many advantages having the possibility of guidance of light through hollow core makes them showing new perspectives in fiber lasers, non-linear optical fibers, generation of super-continuum fiber sensors and particle guidance [30, 31].

The present paper discusses the qualitative treatment of the fiber optic refractive index sensor operating at a range of temperatures spreading from 10^{o}C to 60^{o}C using PCS fibers and a uniform U-shaped glass rod. By generating a calibrated curve relating power output with the concentration of liquids at various temperatures which in turn related to refractive index using binary liquids, the sensor is intended to sense the refractive index of various liquids either dark or transparent operating with high sensitivity.

EXPERIMENTAL DETAILS

The block diagram of the experimental setup consists of the following components

Light source: Laser light source of 660nm

Power meter: Benchmark optical power meter compatible withthe light source

Optical fiber: Plastic clad silica optical fibers of 200/230µm

Connectors: SMA 905 connectors

Chemicals: Benzene and tert-Butanol

Burette system: a couple of burettes fixed to stands vertically

Refractometer: Automatic digital refractometer (RX-7000i)

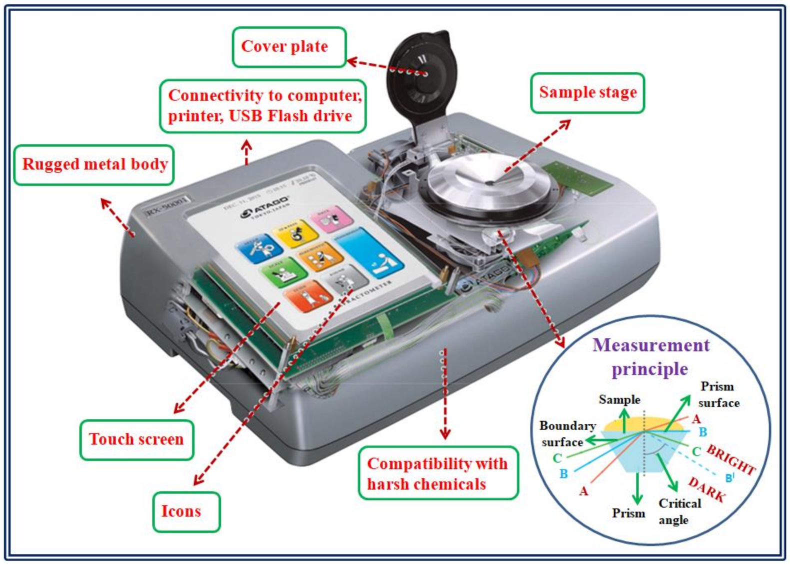

Fig.-1: Automatic digital refractometer of model number RX-7000i

U-shaped glass rod of specific dimensions:

The thickness of rod:	0.5mm
Total height of the glass rod(H):	40mm
Depth of the glass rod immersed in liquid(h):	10mm, 20mm, 30mm
Width between two prongs(Z):	5mm
The radius of the Curvature(X):	2.5mm
Depth of the Curvature(Y):	2.5mm
The total length of the glass rod immersed in liquid:	27.86mm, 47.86mm, 67.86mm

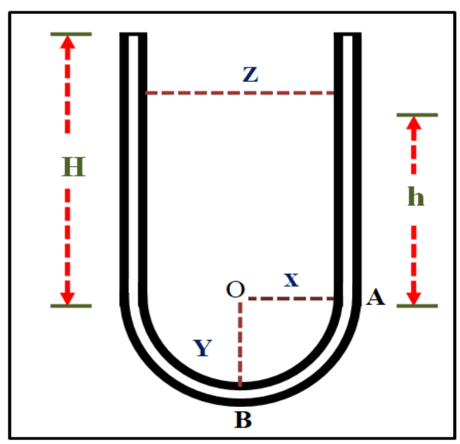

Fig-2: Geometrical parameters of U-shaped glass rod

The sensor is designed by creating a sensing zone using a uniform U-shaped solid glass rod at the middle of the fiber which in turn is connected toa laser light source of 660nm wavelength on one side and a benchmark optical detector on the other side. A set of chemical mixtures with the combination of two liquids Benzene and tert-Butanol were prepared in equal proportions employing a two burette setup. The binary mixtures are prepared by taking different ratios and making the total volume equal to 20ml.

Part-I: Depth of immersion of U-shaped glass rod into the liquid mixture as 1cm: In the first part of the experimentation the light is injected into the first fiber reaching the detector through the second fiber via the glass rod which is surrounded by a specific ratio of the binary mixture was recorded at 10^{o}C initially. The method of recording the output power was repeated by surrounding various binary mixtures around the U-shaped glass rod at 10^{o}C. By raising the temperature of the liquid surrounding the U-shaped glass rod in step of 5^{o}C each time, the output power reaching the detector for the temperatures up to 60^{o}C was recorded and tabulated by fixing the depth of immersion as 1cm.

Part-II: Depth of immersion of U-shaped glass rod into the liquid mixture as 2cm: To enhance the study, the experimental work has been undertaken by increasing the depth of immersion of glass rod into the binary liquid mixture was increased to 2cm. By increasing the depth of immersion of the glass rod into the liquid, the interaction length between the light travelling through the glass rod and the liquid cladding that surrounds the glass rod will be increased, thereby the sensitivity of the sensor is increased since the sensitivity increases with an increase in length of interaction.

Part-III: Depth of immersion of U-shaped glass rod into the liquid mixture as 3cm: The depth of immersion of U-shaped glass rod into the binary liquid mixture was further increased to 3 cm in order to enhance the sensitivity of the sensor.

Part-IV: Determination of Refractive index: In the fourth part of the experimentation the refractive index values of each binary mixture were determined at various temperatures from 10^{o}C to 60^{o}C employing an Automatic digital refractometer which operates with an inbuilt sodium lamp.

RESULTS AND DISCUSSION

The mole fractions corresponding to every mixture with different ratio was calculated theoretically using the formula.

Mole Fraction (X_1) = $\frac{\text{Number of moles of substance}-1}{\text{Total number of moles}}$

Mole Fraction (X_1) = $\frac{\text{Number of moles of substance}-1}{\text{Number of moles of substance}-1+\text{Number of moles of substance}-2}$

Number of moles = $\frac{\text{Mass of substance}}{\text{Mass of one-mole substance}}$

Number of moles = $\frac{\text{Volume} \times \text{Density}}{\text{Molar mass}}$

$X_1 = V_1(\rho_1/M_1)$

∴ Mole Fraction (X_1) = $\frac{V_1(\rho_1/M_1)}{V_1(\rho_1/M_1)+V_2(\rho_2/M_2)}$

Where: M_1, M_2: Molecular weights of chemicals ($kg.mole^{-1}$)

ρ_1, ρ_2: Densities of chemicals ($kg.m^{-3}$)

V_1, V_2: Volumes of chemicals (liters)

The mole fractions of all the binary mixtures have been calculated and tabulated. From the data of mole fractions and refractive indices of all the mixtures at various temperatures (10°C – 60°C) a graph was plotted [fig.-3].

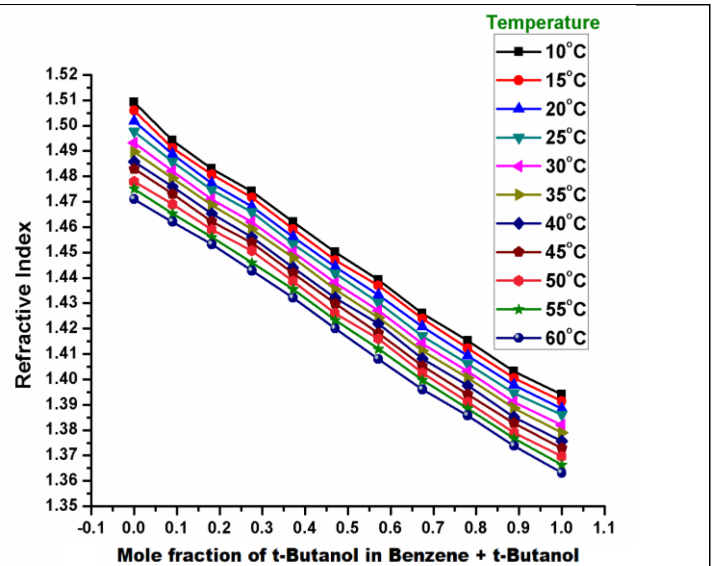

Fig.3: Relation between Mole fraction of tert-Butanol in Benzene + tert-Butanol mixture and Refractive index.

From the graph [fig.-3] it is observed that, as the mole fraction of tert-Butanol in Benzene+tert-Butanol mixture increases, the refractive index decreases, which trend was observed at all the temperatures ranging from 10°C to 60°C.

The concentrations percentage of tert-Butanol in the binary mixtures of Benzene and tert-Butanol were calculated for all the mixtures and the values are tabulated. Now, from the data of concentrations percentage and refractive indices at various temperatures a graph was plotted [fig.-4].

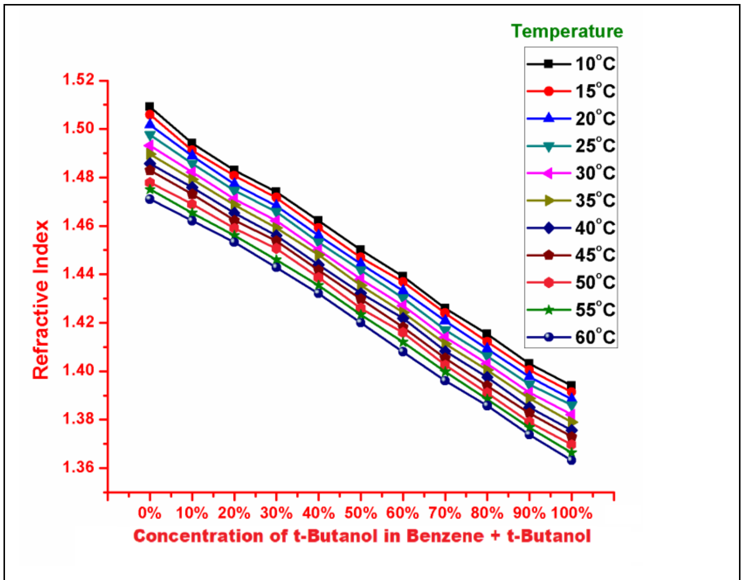

Fig.4: Relation between Concentration (%) of tert-Butanol in Benzene + tert-Butanol mixture and Refractive index.

The variation of refractive index with increasing the concentration percentage of tert-Butanol in Benzene+tert-Butanol mixture shows that the refractive index decreases as concentration increases at all the temperatures.

By considering the various temperatures and corresponding refractive indices values of all the binary mixtures a graph is plotted [fig.-5].

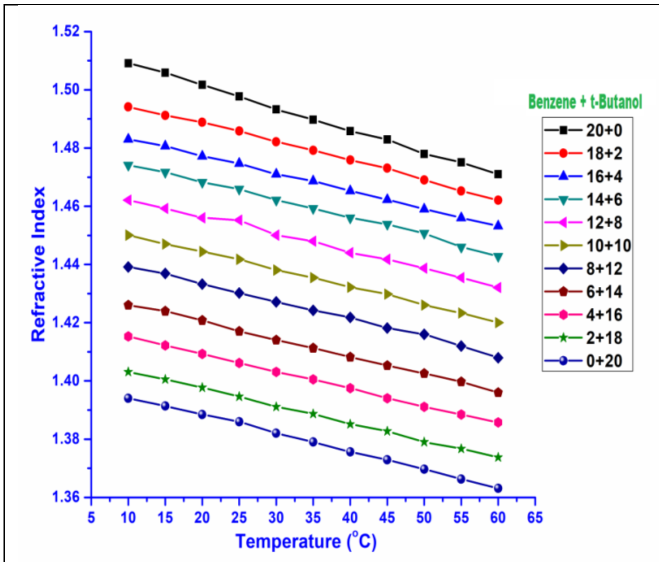

Fig.5: Relation between Temperature and Refractive index of Benzene + tert-Butanol mixtures.

From graph [fig.-5] it is observed that as the temperature of liquid mixtures increases the refractive index of the binary mixture decreases.

To show the mutual dependence of mole fractions, refractive index and temperature a 3dimentional (3D) [fig.-6] graph is plotted to take each parameter along a different axis.

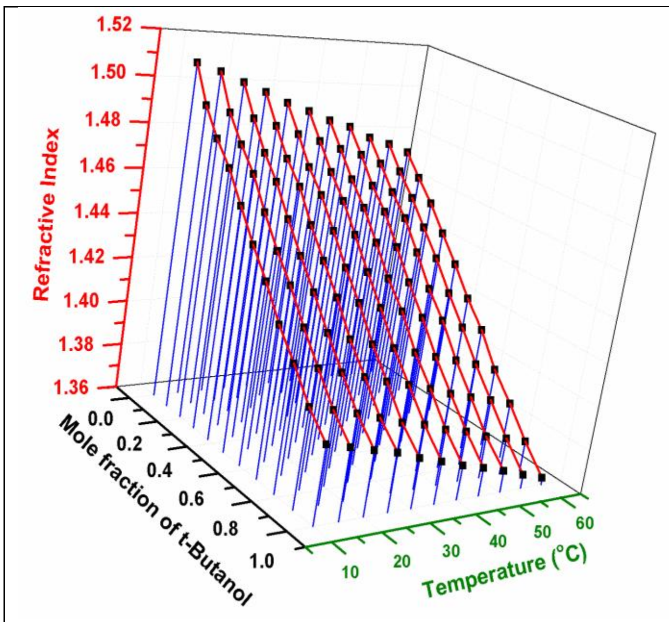

Fig.6: Relation between Mole fraction of tert-Butanol in Benzene + tert-Butanol mixture, Refractive index and

Temperature.

To compare the sensitivities of the sensor, separate graphs are plotted [fig.7-9] between output powers versus mole fraction of tert-Butanol in binary mixtures corresponding to each depth of immersion (1cm, 2cm, 3cm) of the U-shaped glass rod into liquid mixture at different temperatures.

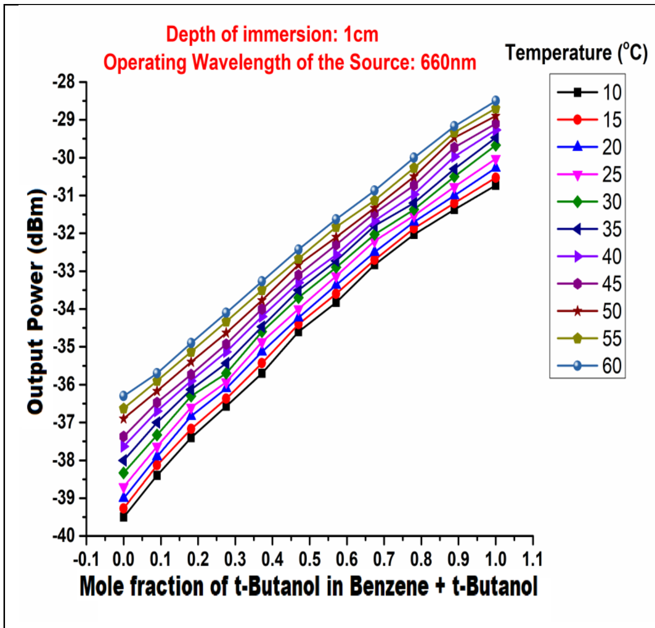

Fig.7: Relation between Mole fraction of tert-Butanol in Benzene + tert-Butanol mixture and Output power at depth of immersion is 1cm.

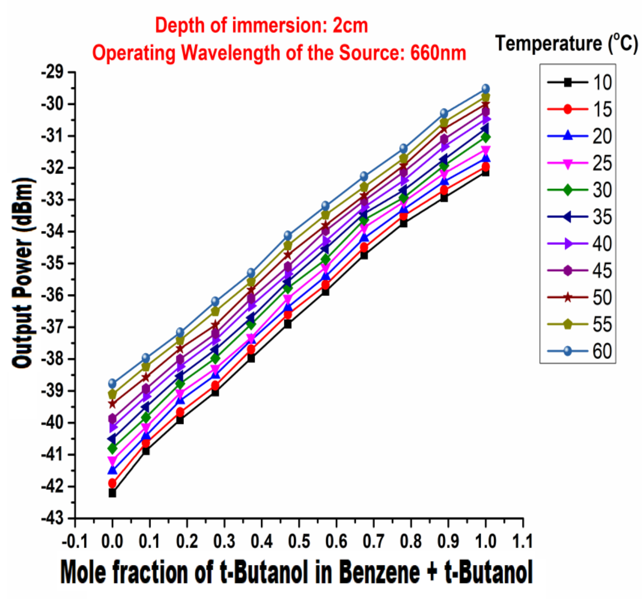

Fig.8: Relation between Mole fraction of tert-Butanol in Benzene + tert-Butanol mixture and Output power at depth of immersion is 2cm.

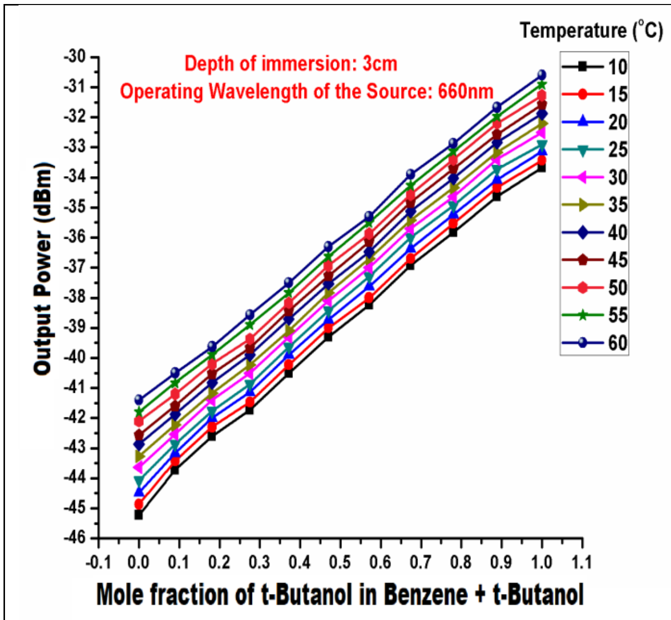

Fig.9: Relation between Mole fraction of tert-Butanol in Benzene + tert-Butanol mixture and Output power at depth of immersion is 3cm.

To study the variation of output power with respect to temperature, graphs are plotted [fig-10-12] between temperature and output power corresponding to each depth of immersion of glass rod into Benzene+tert-Butanol mixtures.

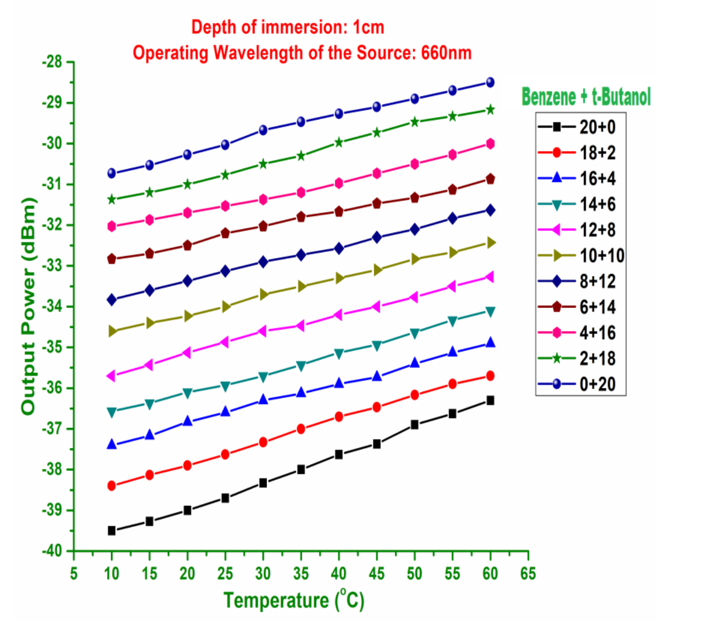

Fig.10: Relation between Temperature and Output power of Benzene + tert-Butanol mixture at depth of immersion is 1cm

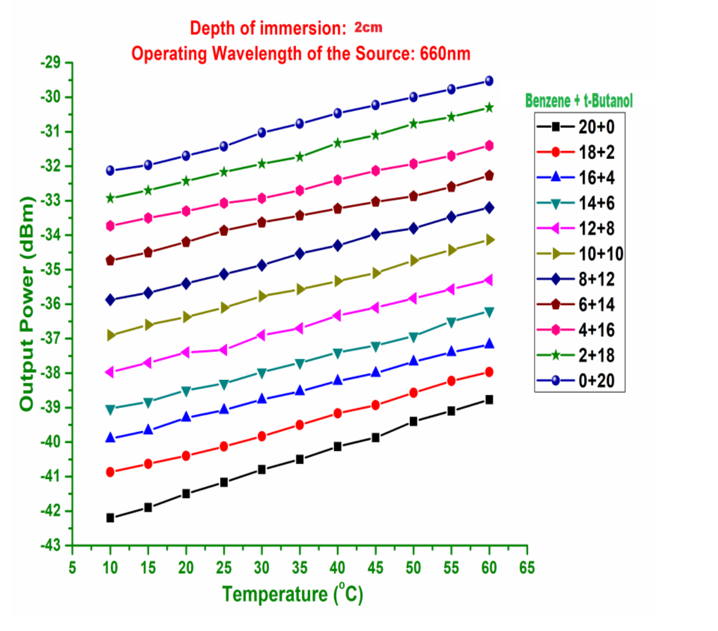

Fig.11: Relation between Temperature and Output power of Benzene + tert-Butanol mixture at depth of immersion is 2cm

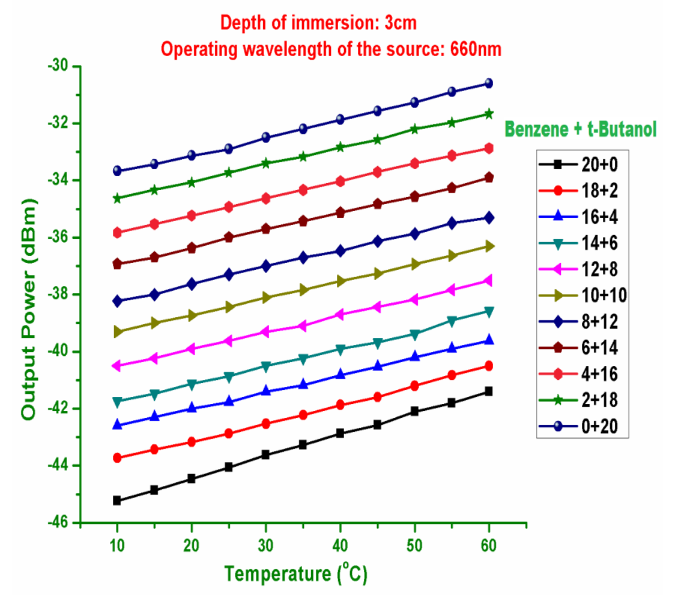

Fig.12: Relation between Temperature and Output power of Benzene + tert-Butanol mixture at depth of immersion is 3cm

The curve shows that as the temperature increases, the output power also increases irrespective of the depth of immersions. 3dimentional (3D) graphs are plotted [fig.13-15] relating refractive index, temperature and output power at different depths of immersions.

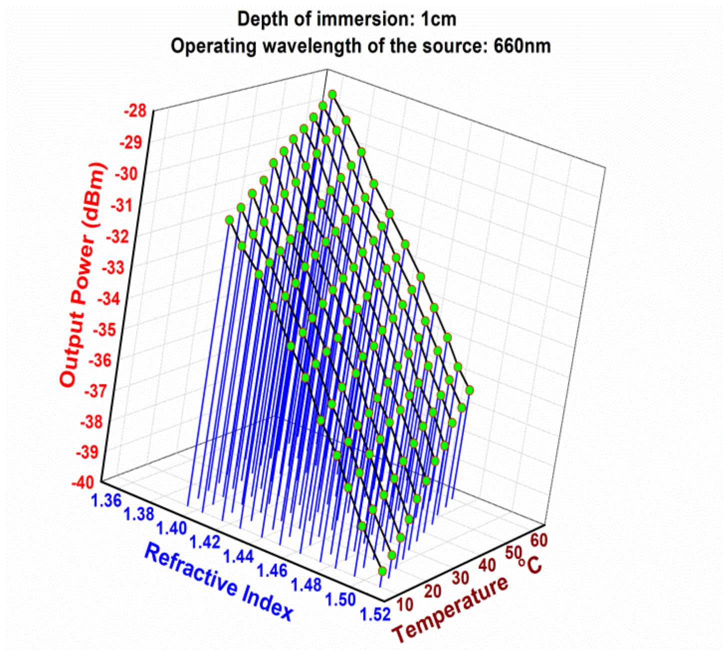

Fig.13: Relation between Refractive index, Output Power and Temperature of Benzene + tert-Butanol at depth of immersion is 1cm

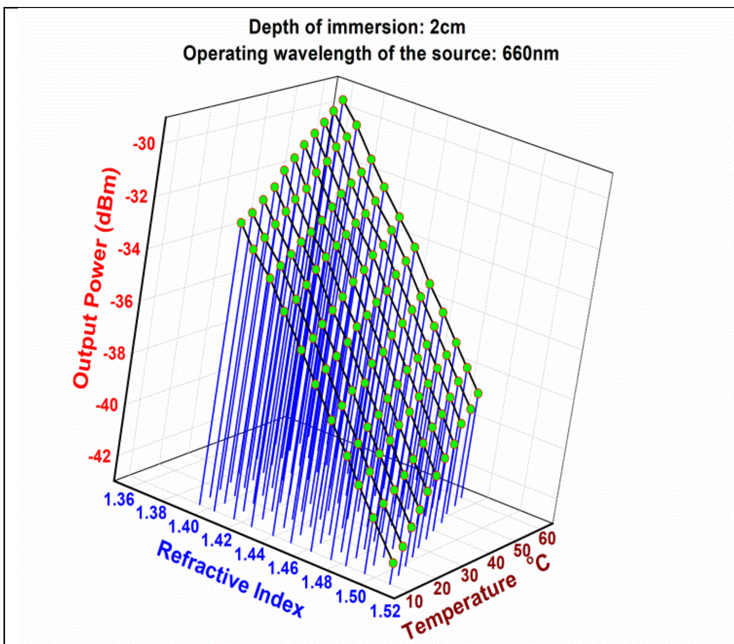

Fig.14: Relation between Refractive index, Output Power and Temperature of Benzene + tert-Butanol at depth of immersion is 2cm

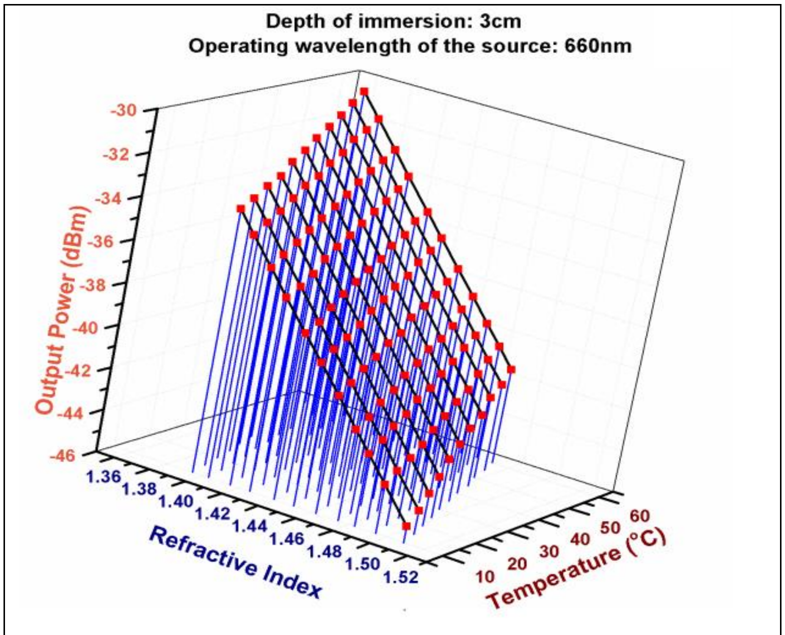

Fig.15: Relation between Refractive index, Output Power and Temperature of Benzene + tert-Butanol at depth of immersion is 3cm

CONCLUSION

The present work is undertaken to study the refractive index of liquids either dark or transparent at different temperatures using the binary mixtures of Benzene and tert-Butanol. The calibrated graphs are plotted between refractive index and output power at various temperatures using a semiconductor laser diode light source of 660nm maintaining the depth of immersion of the glass rod into the liquid mixture as 1cm. By studying the sensitivities through the trend of the curves at different depths of immersions, it is concluded that as the depth of immersion increases, the sensitivity of the sensor increases. Hence, from the present work, it can be concluded that the sensor with a 3cm depth of immersion of the glass rod into the liquid mixture offers the highest sensitivity in the determination of refractive indices of liquids either dark or transparent.

REFERENCES

[1]L. Nykanen and H. Suomalainen, Aroma of Beer, Wine and Distilled Alcoholic Beverages, Akademie, Berlin, Germany, 1983.

[2] P. Zu, C. C. Chan, Y. Jin, et al., “A temperature-insensitive twist sensor by using low-birefringence photonic-crystalfiber-based Sagnac interferometer,” IEEE Photonics Technology Letters, vol. 23, no. 13, pp. 920–922, 2011.

[3] R.S. Medlock, “Fibre Optic Intensity Modulated Sensors” in “Optical Fibre Sensors”, Ed. By A.N. Chester, S. Martelluci and A.M. Verga Scheggi, Martinus Nijhoff, Dordrecht (1987).

[4] A. Weinert, Plastic Optical Fibers, Publics MCD, Munich, Germany, 1999.

D.A. Krohn, “Fibre Optic Sensors-Fundamentals and Applications”, Instrument Society of America (1988).

[5] X. Yu, P. Shum, S. Fu, and L. Deng, “Torsion-sensitivity of a mechanical long-period grating in photonic crystal fiber,” Journal of Optoelectronics and Advanced Materials, vol. 8, no. 3, pp. 1247–1249, 2006.

[6] Y. Miao, B. Liu, K. Zhang, Y. Liu, and H. Zhang, “Temperature tunability of photonic crystal fiber filled with fe3o4 nanoparticle fluid,” Applied Physics Letters, vol. 98, no. 2, Article ID 021103, 2011.

[7] Y. Yu, X. Li, X. Hong et al., “Some features of the photonic crystal fiber temperature sensor with liquid ethanol filling,” Optics Express, vol. 18, no. 15, pp. 15383–15388, 2010.

[8] R.N. Chakraborty and Pal B.P., Internal Study on “Development of a Fibre Optic Fusion Splicing Machine”, IIT Delhi (1985).

[9] Y. G. Han, “Temperature-insensitive strain measurement using a birefringent interferometer based on a polarization-maintaining photonic crystal fiber,” Applied Physics B, vol. 95, no. 2, pp. 383–387, 2009.

[10] POF Consortium in Japan, Ed., Plastic Optical Fiber, Kyoritsu, Tokyo, Japan, 1997.

[11] J. Dakin and B. Culshaw, Optical Fiber Sensors, vol. 4, Artech House, Boston, Mass, USA, 1997.

[12] S. Muto, O. Suzuki, T. Amano, and M. Morisawa, “A plastic optical fiber sensor for real-time humidity monitoring,” Measurement Science and Technology, vol. 14, no. 6, pp. 746–750, 2003.

[13] Z. He, F. Tian, Y. Zhu, N. Lavlinskaia, and H. Du, “Long-period gratings in photonic crystal fiber as an optofluidic label-free biosensor,” Biosensors and Bioelectronics, vol. 26, no. 12, pp. 4774–4778, 2011.

[14] G.D. Pitt, Extance P., Neat R.C., Batchelder D.N., Jones R.E., Barnett J.A. and Pratt R.H., “Optical Fibre Sensors”, Proc. IEE 132, pt. J., 214-218 (1985).

[15] M. Morisawa, Y. Amemiya, H. Kohzu, C. X. Liang, and S. Muto, “Plastic optical fiber sensor for detecting vapour phase alcohol,” Measurement Science and Technology, vol. 12, no. 7, pp. 877– 881, 2001.

[16] E. Peynaud, Knowing and Making Wine, John Wiley & Sons, New York, NY, USA, 1984.

[17] C. Lecaplain, B. Ortac¸, G. MacHinet, et al., “High-energy femtosecond photonic crystal fiber laser,” Optics Letters, vol. 35, no. 19, pp. 3156–3158, 2010.

[18] D. G. Ouzounov, F. R. Ahmad, D. Muller, et al., “Generation ¨ of megawatt optical solitons in hollow-core photonic bandgap fibers,” Science, vol. 301, no. 5640, pp. 1702–1704, 2003.

[19] W. Qian, C. L. Zhao, X. Dong, and W. Jin, “Intensity measurement-based temperature-independent strain sensor using a highly birefringent photonic crystal fiber loop mirror,” Optics Communications, vol. 283, no. 24, pp. 5250–5254, 2010.

[20] D. Chen and L. Shen, “Switchable and tunable erbium-doped fiber ring laser incorporating a birefringent and highly nonlinear photonic crystal fiber,” Laser Physics Letters, vol. 4, no. 5, pp. 368–370, 2007.

[21] F. Benabid, J. C. Knight, G. Antonopoulos, and P. S. J. Russell, “Stimulated Raman scattering in hydrogen-filled hollow-core photonic crystal fiber,” Science, vol. 298, no. 5592, pp. 399– 402, 2002.

[22] T. G. Euser, M. K. Garbos, J. S. Y. Chen, and P. S. J. Russell, “Precise balancing of viscous and radiation forces on a particle in liquid-filled photonic bandgap fiber,” Optics Letters, vol. 34, no. 23, pp. 3674–3676, 2009.

[23] C.M. Davis, Carome E.E., Weil M.H., Ezekiel S. and Einzig R.E., “ Fibre Optic Sensors Technology Handbook”, Dynamic Systems Inc., Virginia (1982).

[24] W. Jin, H. F. Xuan, and H. L. Ho, “Sensing with hollow-core photonic bandgap fibers,” Measurement Science and Technology, vol. 21, no. 9, Article ID 094014, 2010.

[25] L. Jin, W. Jin, and J. Ju, “Directional bend sensing with a co2 long-period grating in a photonic crystal fiber,” Journal of Lightwave Technology, vol. 27, no. 21, pp. 4884–4891, 2009.

[26] J. Villatoro, V. P. Minkovich, and D. Monzon-Hern ́ Mendez, ́ “Temperature-independent strain sensor made from tapered holey optical fiber,” Optics Letters, vol. 31, no. 3, pp. 305–307, 2006.

[27] H. Zhang, B. Liu, Z. Wang, et al., “Temperature-insensitive displacement sensor based on high-birefringence photonic crystal fiber loop mirror,” Optica Applicata, vol. 40, no. 1, pp. 209–217, 2010.

[28] P. Russell, “Applied physics: photonic crystal fibers,” Science, vol. 299, no. 5605, pp. 358–362, 2003.

[29] K. T. V. Grattan and T. Sun, “Fiber-optic sensor technology: an overview,” Sensors and Actuators A, vol. 82, no. 1, pp. 40– 61, 2000.

[30] S. Arismar Cerqueira, “Recent progress and novel applications of photonic crystal fibers,” Reports on Progress in Physics, vol. 73, no. 2, Article ID 024401, 2010

[31] P. R. Laurent Bigot and P. Roy, “Fibers a cristal photonique: ` 10 ans d’existence et un vaste champ d’applications,” Images de la physique, pp. 71–80, 2007.