ISSN: 0974-5823 Vol. 7 No. 4 April, 2022

International Journal of Mechanical Engineering

Wavelength Tunable Light Mechanism Enabled Extrinsic Fiber Optic Sensor for the Determination of Refractive Index of Liquids at the Temperature Range between 10^{o}C and 60^{o}C

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

Corresponding Author: S. Srinivasulu

[1&2] Department of Physics, College of Engineering Hyderabad, J N T University Hyderabad – 500085, Telangana State, India.

ABSTRACT: The light based fiber optic sensors have become highly popular in the measurement of unlimited number of environmental parameters during the last few decades across the globe, due to wide range of advantages in terms of cost, reliability, sensitivity, ruggedness, high precision, versatility etc. in measuring the parameters. The present paper describes an intensity modulated fiber optic refractive index sensor using a tunable light source for the determination of refractive index of liquids at the temperature range of 10^{o}C and 60^{o}C involving the evanescent wave mechanism at the region of sensing. The tunable light source was connected at one end of the input fiber leg and the power meter was connected at one end of the output fiber leg. A U-shaped glass rod connected between both input and output fiber legs as an extrinsic sensing probe, which when exposed to a liquid of particular refractive index influence the light reaching at the output end. The relationship thus formed between liquid surrounding the U-shaped glass rod and the power reaching the detector at various temperatures was used to develop a sensor to determine the refractive index of liquids at various temperatures and at the tunable wavelengths of 630nm, 660nm, 820nm and 850nm.

Keywords: *Evanescent wave mechanism, Fiber optic sensor, Refractive index, Sensing probe, Temperature range of 10^{o}C to 60^{o}C, Tunable light source, U-shaped glass rod.*

INTRODUCTION

The behavior of most of the liquids can be characterized by a single parameter i.e., refractive index at a particular temperature and wavelength. Several methods and design schemes have been adopted for the measurement of refractive index in various fields [1, 2]. The light refraction of turbid dispersions were of interest to chemists and physicists for more than 5 decades [3-5]. The traditional methods for the measurement of refractive index from Brewster angle and critical angle data ran into certain difficulties for turbid and absorbing liquids [6-23]. The spectroscopic data of turbidity and light scattering analysis data of particulate suspension or polymeric data requires the refractive index values of particle suspension [24]. The refractive index data of suspension in turbid liquids requires the determination of refractive index of particle suspension in liquids. The determination of small refractive index changes in the liquids of smaller volumes is needed in case bio-sensing. Classical methods of using bulk refractometers then are not appropriate. Sometimes the weights and size becomes inconvenient for this case and in other applications. Therefore the sensors constructed with the help of optical fibers become relevant as alternative members. Optical fiber based refractive index sensors are suitable for measuring the parameter from remote and are very compact in terms of size. They can be used as chemical sensors for liquids or composites which needs very small volume. Optical fiber sensors are also were used as absorption sensors for the measurement of various liquid parameters [25-28]. The surface plasmon technique using fibers with metal coating and using Bragg gratings in fibers, it is possible to achieve high sensitivity in the measurement of refractive index [29-32]. Higher sensitivities in measurement of refractive index of liquids can also be obtained by stripping of cladding of the fiber and fiber tapering in the design can be used [33-38]. The refractive index sensors also can be developed by depositing the thin films on them without tapering and maintaining the fiber as fully cladded [39, 40]. A fiber with cladding stripped off was deposited with material of absorbing nature using Sol-gel technique becomes sensitive to chemicals which get absorbed by the adsorbent layer and modifies its refractive index [41-48].

The U-shaped glass rod with specific dimensions connected at some portion of the fiber along its length can be used to determine the refractive index of liquids as an extrinsic fiber optic sensor. In the extrinsic fiber optic sensor, the light modulation i.e., modulation of any one of its parameter like intensity, phase, wavelength and frequency modulates outside the fiber. In the present case intensity modulation of light takes place in the light transmitted through the U-shaped glass rod. During its transmission through glass rod a part of light will be absorbed by the liquid surrounding the glass rod as an evanescent wave whose magnitude becomes function of the refractive index of the liquid. By calibrating the sensor by recording the refractive index and corresponding output powers of various liquids at different temperatures and at different wavelengths and thereby mapping the output power and refractive indices the design can be used to measure the refractive index of various unknown liquids.

EXPERIMENTAL DETAILS

The experimentation was proposed to be carried out broadly in two parts. In the first part the experiment was carried out at various temperatures ranging from 10ºC to 60ºC and in the second part the experiment was taken using various wavelengths of light source i.e., 630nm, 660nm, 820nm and 850nm. In order to calibrate the fiber optic sensor at the temperature range of 10ºC to 60ºC and at various wavelength of 630nm, 660nm, 820nm and 850nm, a range in the refractive index of liquid mixtures prepared with a set of binary liquids i.e., Methanol and Benzene have been used.

A couple of plastic clad silica (PCS) fibers of equal dimensions have been used, one as input fiber arm and the other as output fiber arm in the experimental setup. A tunable light source which can be tuned to 630nm, 660nm, 820nm and 850nm was connected to one end of the input fiber arm by using suitable SMA 905 connector and a power meter was connected to one of ends of the output fiber arm. A U-shaped glass rod of specific dimensions was connected between the two fiber arms.

Liquid mixtures have been prepared using Methanol and Benzene at different proportions making total volume equivalent to 20ml. Fixing the depth of immersion of U-shaped glass rod into liquid as 3cm, light launched into fiber tuning the source to one of the wavelengths (630nm), the light reaching the detector was noted and recorded corresponding to a mixture of 0ml Methanol + 20ml Benzene at 10ºC. Using same set of mixture and using same wavelength the above method was repeated for increasing the temperatures to 15ºC, 20ºC, 25ºC, 30ºC, 35ºC, 40ºC, 45ºC, 50ºC, 55ºC, 60ºC.

Now changing the proportional quantities of binary liquids to 2ml Methanol + 18ml Benzene the experiment was repeated with same wavelength 630nm and rising the temperatures from 10ºC to 60ºC. Similarly the method of experimentation was repeated with the binary mixtures with other proportions (4ml+16ml, 6ml+14ml, 8ml+12ml, 10ml+10ml, 12ml+8ml, 14ml+6ml, 16ml+4ml, 18ml+2ml, 20ml+0ml).

As a second part of the experiment the source was tuned to 660nm wavelength and the entire procedure of performing the experiment was carried out and the output powers are noted. The similar method was followed by tuning the source wavelength to the values of 820nm and 850nm.

Refractive indices of all the mixtures of Methanol and Benzene was measured by using a automatic digital refractometer RX-7000i (Atago make, Japan) at the temperature range between 10ºC to 60ºC and values are recorded.

RESULTS AND DISCUSSION

From the entire data that is collected during the experimentation, various parameters have been mapped one another graphically to analysis dependence of one parameter on the other. Initially it is expected that the mole fraction of binary mixtures play crucial role in deciding the refractive index of various mixtures and hence the related output power. Therefore in graph-1 [fig-1], the mole fraction of Methanol in the various binary mixtures and the corresponding refractive indices have plotted and the relationship was shown to be linear and as the mole fraction of Methanol increases in the mixtures the refractive index decreases and the magnitude of relationship between refractive index and mole fraction decreases from 10ºC to 60ºC.

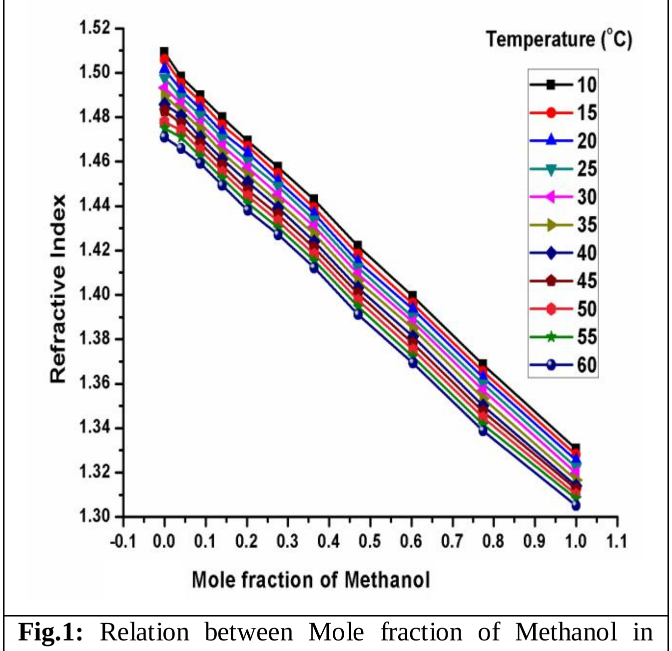


Fig.1: Relation between Mole fraction of Methanol in Benzene + Methanol solution and Refraction index.

In the second graph [fig-2] the refractive index variations with respect to temperature from 10ºC to 60ºC have been shown. It is observed that for various mixtures, as temperature increases the refractive index decreases.

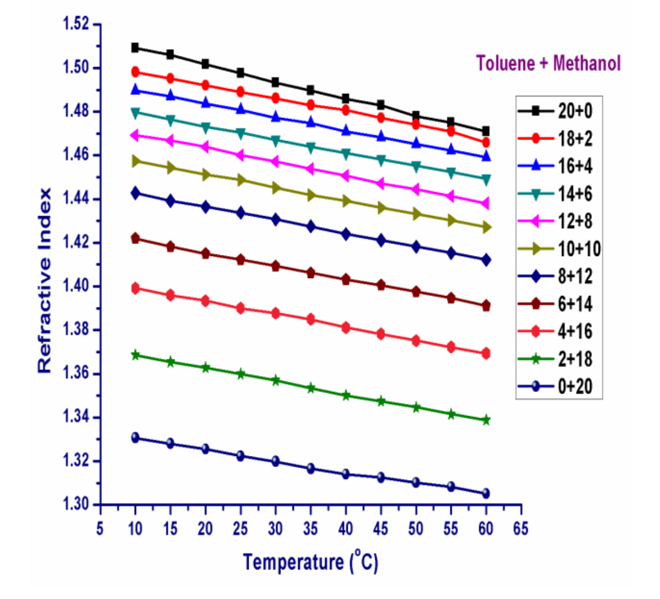


Fig.2: Relation between Temperature and Refraction index of Benzene + Methanol solution.

With a view to study the combined effect of mole fraction of Methanol in the binary mixture, refractive indices and the temperature a 3D graph was plotted among them in graph-3 [fig-3].

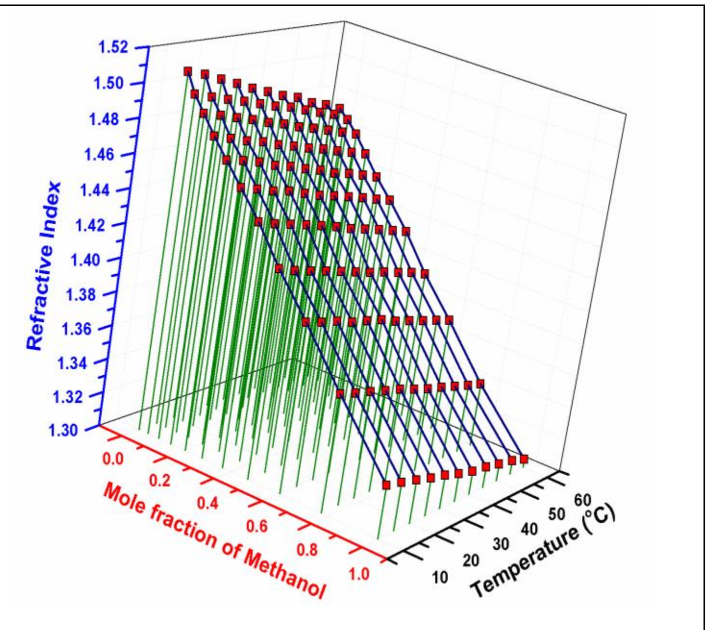


Fig.3: Relation between Mole fraction of Methanol in Benzene + Methanol solution, Refraction index and Temperature.

The mole fraction of Methanol in all the binary mixtures were related to output power at various wavelengths (630nm, 660nm, 820nm and 850nm) corresponding to different temperatures were shown to be linear in all cases [fig 4-7].

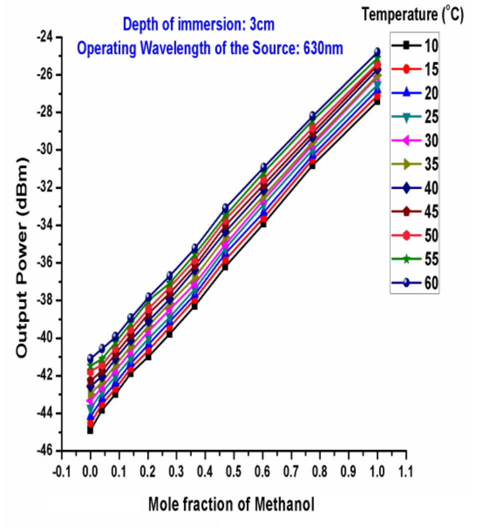


Fig.4: Relation between Mole fraction of Methanol in Benzene + Methanol solution and Output power for operating wavelength of the source 630nm.

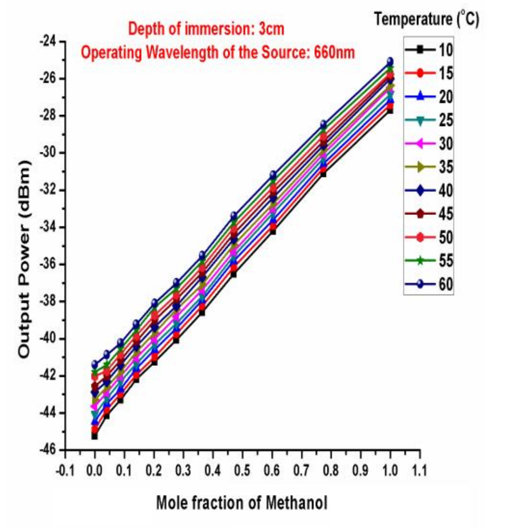


Fig.5: Relation between Mole fraction of Methanol in Benzene + Methanol solution and Output power for operating wavelength of the source 660nm.

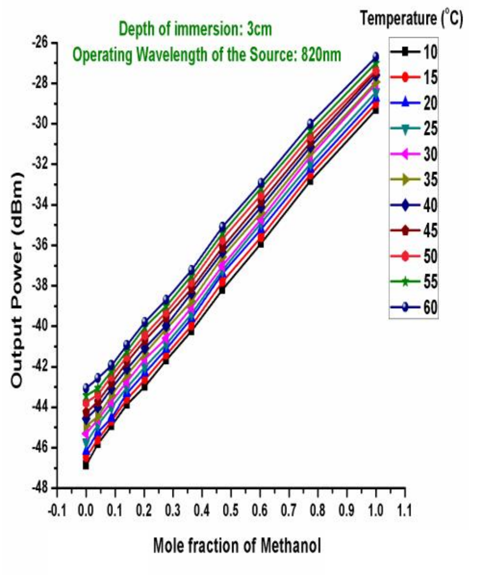


Fig.6: Relation between Mole fraction of Methanol in Benzene + Methanol solution and Output power for operating wavelength of the source 820nm.

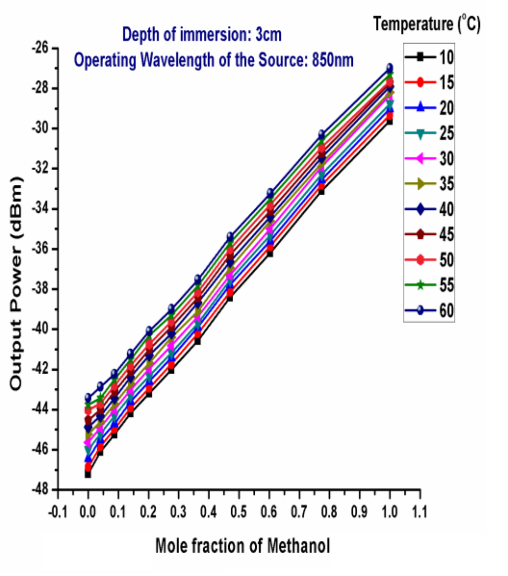
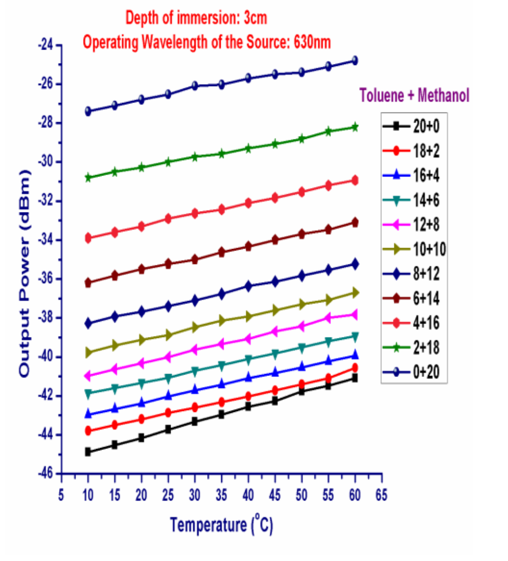


Fig.7: Relation between Mole fraction of Methanol in Benzene + Methanol solution and Output power for operating wavelength of the source 850nm.

The relationships between temperature and output power corresponding to various mixtures at different temperatures (10ºC to 60ºC) and at different wavelengths (630nm, 660nm, 820nm and 850nm) were shown to be linear and as temperature increases the output also increases in all cases [fig 8-11].



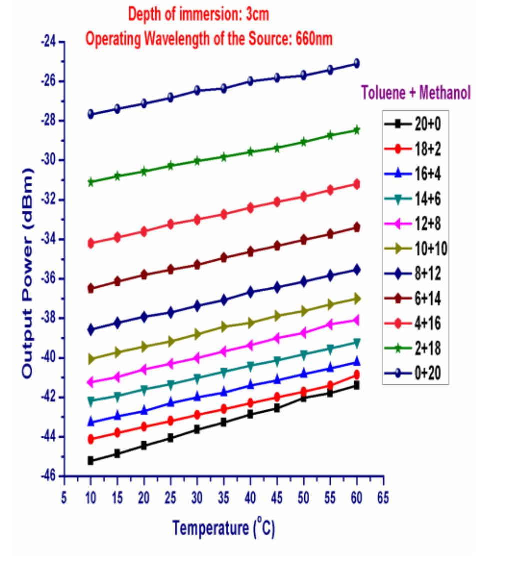
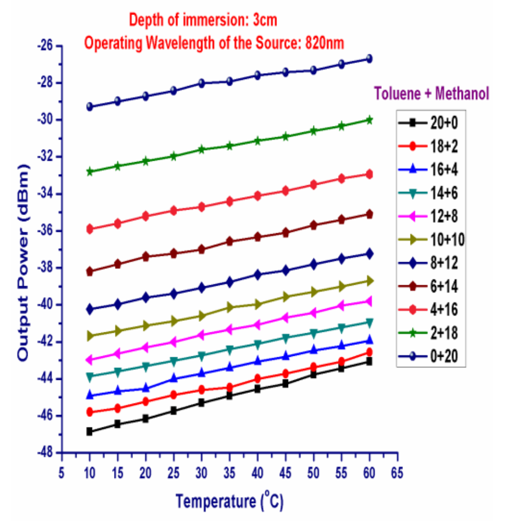


Fig.8: Relation between Temperature and Output power of Benzene + Methanol solution for operating wavelength of the source 630nm.

Fig.9: Relation between Temperature and Output power of Benzene + Methanol solution for operating wavelength of the source 660nm.



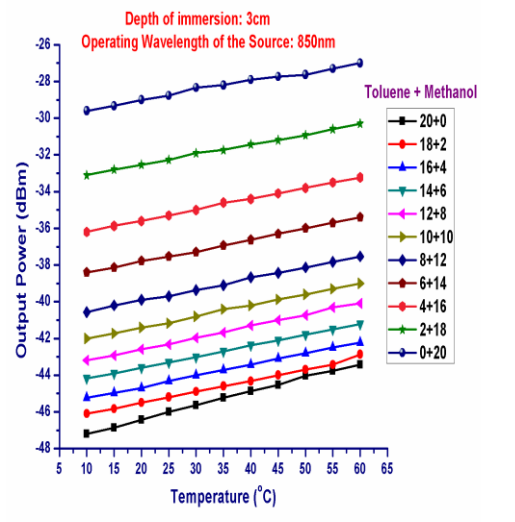


Fig.10: Relation between Temperature and Output power of Benzene + Methanol solution for operating wavelength of the source 820nm.

Fig.11: Relation between Temperature and Output power of Benzene + Methanol solution for operating wavelength of the source 850nm.

To observe the correlations among the output power, refractive index and temperature of all mixtures corresponding to all the wavelengths i.e., 630nm, 660nm, 820nm and 850nm were presented in 3-D graphs [fig 12-15].

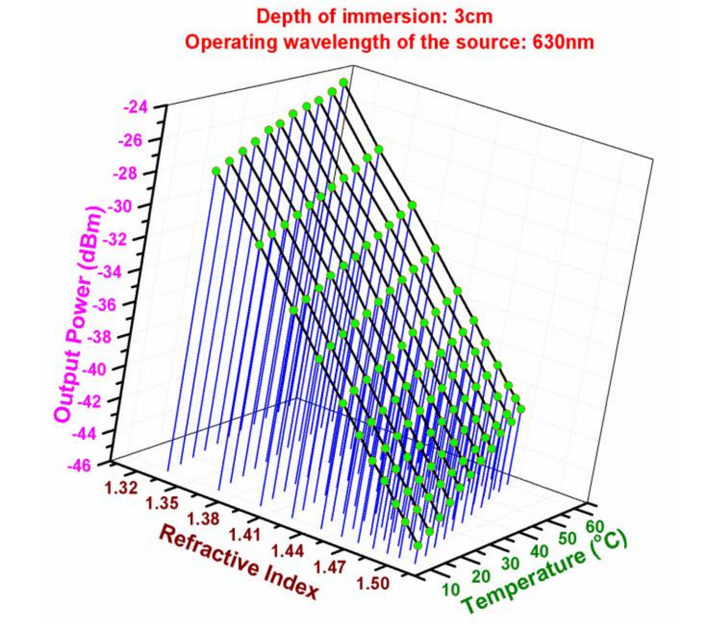


Fig.12: Relation between Refractive index, Output Power and Temperature of Benzene + Methanol solution for operating wavelength of the source 630nm.

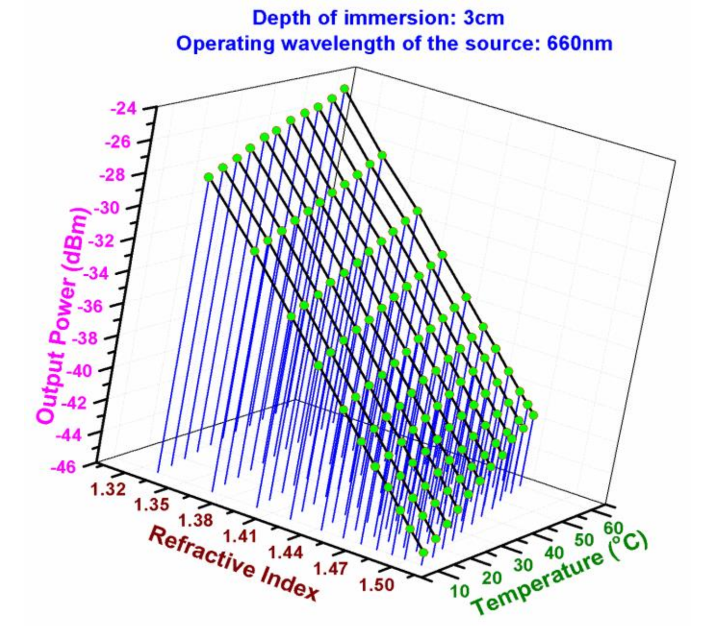


Fig.13: Relation between Refractive index, Output Power and Temperature of Benzene + Methanol solution for operating wavelength of the source 660nm.

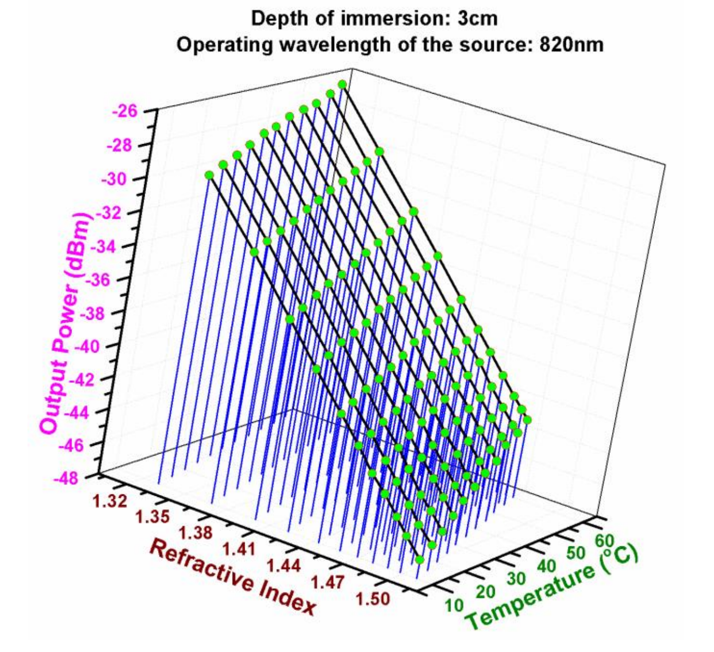


Fig.14: Relation between Refractive index, Output Power and Temperature of Benzene + Methanol solution for operating wavelength of the source 820nm.

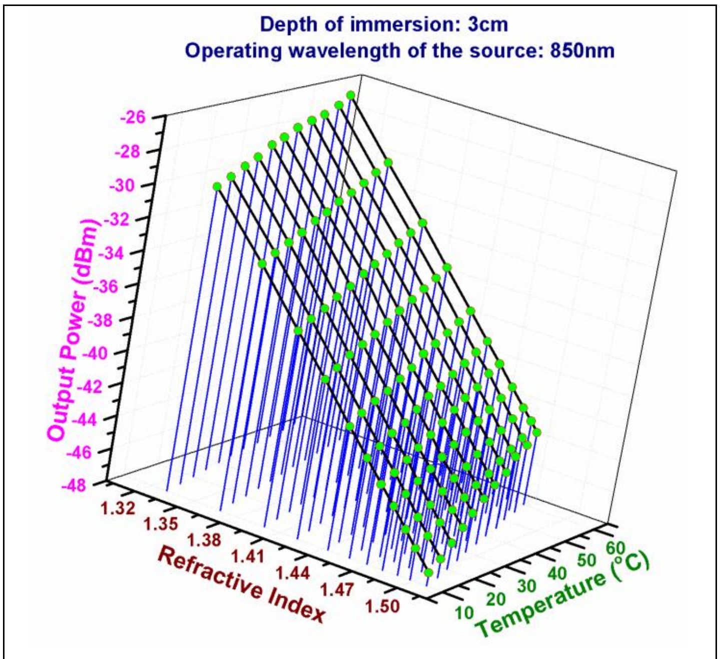


Fig.15: Relation between Refractive index, Output Power and Temperature of Benzene + Methanol solution for operating wavelength of the source 850nm.

CONCLUSION

- In the present work, a refractometer was calibrated and developed to operate at temperatures between 10ºC to 60ºC and at wavelengths of 630nm, 660nm, 820nm and 850nm to determine the refractive index of various dark and transparent liquids.
- A set of binary liquids i.e., Methanol and Benzene has been chosen to prepare a range of test liquid mixtures having different indices of refraction, in the calibration of the evanescent wave absorption based fiber optic sensor.
- The data corresponding to output powers related to all the mixtures with various refractive indices maintained around the U-shaped glass rod at the temperature range between 10ºC to 60ºC and at the wavelengths of 630nm, 660nm, 820nm and 850nm have been obtained.
- The present sensor is a unique and versatile refractive index sensor operating at 630nm, 660nm, 820nm & 850nm and at the temperature range of 10ºC to 60ºC which was proved to be superior in many aspects comparing with conventional sensors.

REFERENCES

[1] G.H. Meeten, in: G.H. Meeten (Ed.), Optical Properties of Polymers, Elsevier, London, 1986.

[2] G.F. Stanley, Refractometers: Basic Principles, Bellingham & Stanley Ltd., 1989.

[3] A. Chou, M. Kerker, The refractive index of colloidal sols, J. Phys. Chem. 60 (1955) 562–566.

[4] W. Heller, The determination of refractive indices of colloidal particles by means of a new mixture rule or from measurements of light scattering, Phys. Rev. 68 (1945) 5–10.

[5] B.H. Zimm, W.B. Dandleker, Theory of light scattering and refractive index of solutions of large colloidal particles, J. Phys. Chem. 58 (1954) 644–648.

[6] F. Robillard, A.J. Patitsas, Diameter measurement of Dow latexes EP 1358- 38 by three optical methods, Can. J. Phys. 51 (1973) 2395–2401.

[7] G.H. Meeten, A.N. North, Refractive index measurement of turbid colloidal fluids by transmission near the critical angle, Meas. Sci. Technol. 2 (1991) 441–447.

[8] J.V. Champion, G.H. Meeten, M. Senior, Refractive index of particles in the colloidal state, J. Chem. Soc. Faraday Trans. II 74 (1978) 1319– 1329.

[9] F. Robillard, A.J. Patitsas, Determination of size, size distribution, and refractive index of Dow latexes EP-1358-38 by the Mie scattering method, Can. J. Phys. 52 (1974) 1571–1582.

[10] G.H. Meeten, A.N. North, Refractive index measurement of absorbing and turbid fluids by reflection near critical angle, Meas. Sci. Technol. 6 (1995) 214–221.

[11] S. Srinivasulu, Dr. S. Venkateswara Rao, Application of U-shaped Hybrid Fiber Optic Sensor to Determine the Temperature Dependent Variation of Refractive Index of Binary Liquids, Materials Today: Proceedings, Vol. No. 51, Part No. 1, 2022, 31-37.

[12] M. Nakagaki, W. Heller, Effect of light scattering upon the refractive index of dispersed colloidal spheres, J. Appl. Phys. 27 (1956) 975–979.

[13] J.V. Champion, G.H. Meeten, M. Senior, Optical Turbidity and Refraction in a dispersion of spherical colloidal particles, J. Chem. Soc. Faraday Trans. II 75 (1979) 184–188.

[14] T. Okubo, Refractometric studies of “Liquid-like” and “Crystal-like” colloids in deinonized solution, J. Colloid Interface Sci. 135 (1990) 294–296.

[15] G.H. Meeten, Refractive index of colloidal dispersions of spheroidal particles, J. Colloid Interface Sci. 77 (1980) 1–5.

[16] L. Lewpacher, A. Penzkofer, Refractive index measurement of absorbing condensed media, Appl. Opt. 23 (1984) 1554–1558.

[17] J.V. Champion, G.H. Meeten, M. Senior, Refraction by spherical colloidal particles, J. Colloid Interface Sci. 72 (1979) 471–482.

[18] J.E. Geake, C. Mill, M. Mohammadi, A linear differentiating refractometer, Meas. Sci. Technol. 5 (1994) 531–539.

[19] G.H. Meeten, Refractive index errors in the critical-angle and the Brewsterangle methods applied to absorbing and heterogeneous materials, Meas. Sci. Technol. 8 (1997) 728–733.

[20] A. Killey, G.H. Meeten, Optical extinction and refraction of concentrated latex dispersions, J. Chem. Soc. Faraday Trans. II 77 (1981) 587– 599.

[21] M. Mohammadi, Colloidal refractometry: meaning and measurement of refractive index for

[22] P.R. Jarvis, G.H. Meeten, Angle measurement of refractive index of absorbing material: an experimental study, J. Phys. E. Sci. Instrum. 19 (1986) 296–298.

dispersion: the science that time forgot, Adv. Colloidal Interface Sci. 62 (1995) 17–29.

[23] G.H. Meeten, A.N. North, F.M. Willmouth, Errors in critical angle measurement of refractive index of optically absorbing materials, J. Phys. E. Sci. Instrum. 17 (1984) 642–643.

[24] M. Kerker, The Scattering Light and Other Electromagnetic Radiation, Academic Press, 1969.

[25] B.D. Gupta, C.D. Singh, A. Sharma, Fiber optic evanescent field absorption sensor: effect of launching condition and the geometry of the sensing region, Opt. Eng. 33 (1994) 1864–1868.

[26] V. Ruddy, An effective attenuation coefficient for evanescent wave spectroscopy using multimode fiber, Fiber Integr. Opt. 9 (1990) 142–150.

[27] P.H. Paul, G. Kychakoff, Fiber-optic evanescent field absorption sensor, Appl. Phys. Lett. 51 (1987) 12–14.

[28] V. Ruddy, B.D. MacCraith, J.A. Murphy, Evanescent wave absorption spectroscopy using multimode fibers, J. Appl. Phys. 67 (1990) 6070–6074.

[29] K. Schroeder, W. Ecke, R. Mueller, R. Willsch, A. Andreev, A fiber Bragg grating refractometer, Meas. Sci. Technol. 12 (2001) 757–764.

[30] D. Monzoon-Hernandez, V. Joel, D. Talavera, D. Luna-Moreno, Opticalfiber surface-plasmon resonance sensor with multiple resonance peaks, Appl. Opt. 43 (2004) 1216–1220.

[31] M. Iga, A. Seki, K. Watanabe, Hetero-core structured fiber optic surface plasmon resonance sensor with silver film, Sens. Actuators B B101 (2004) 368–372.

[32] X. Shu, A.L.G. Bashir, Y. Liu, L. Zhang, I. Bennion, Sampled fiber Bragg grating for simultaneous refractive index and temperature measurement, Opt. Lett. 26 (2001) 774–776.

[33] J. Villiatoro, D. Monzoon-Hernandez, D. Talavera, High resolution refractive index sensing with cladded multimode tapered optical fiber, Electron. Lett. 40 (2004) 106–107.

[34] S. Srinivasulu, Dr. S. Venkateswara Rao, U-Shaped Glass Rod as Key Construction materials in the Extrinsic Fiber Optic Sensor to Determine Various Parameters of Liquids at the Operating Wavelength of 660nm, Materials Today: Proceedings, Vol. No. 45, Part No. 7, (2021), 6728-6742.

[35] Y.M. Wong, R.J. Scully, H.J. Kadim, V. Alexiou, R.J. Bartlett, Automation and dynamic characterization of light intensity with applications to tapered plastic optical fiber, J. Opt. A: Pure Appl. Opt. 5 (2003) S51–S58.

[36] M.A. Afromowitz, K.Y. Lam, Fiber-optic epoxy composite cure sensor. II. Performance characteristics, Appl. Opt. 34 (1995) 5639–5643.

[37] A. Kumar, T.V.B. Subrahmonium, A.D. Sharma, K. Thyagarajan, B.P. Pal, I.C. Goyal, Novel refractometer using a tapered optical fiber, Electron. Lett. 20 (1984) 534.

[38] M.A. Afromowitz, K.Y. Lam, The optical properties of curing epoxies and application to the fiber-optic epoxy cure sensor, Sens. Actuators A 21–23 (1990) 1107–1110.

[39] A. Cusano, A. Cutolo, M. Giordano, L. Nicolais, Optoelectronic refractive index measurements: application to smart processing, IEEE Sens. J. 3 (2003) 781–787.

[40] K. Spenner, M.D. Singh, H. Schulte, H.J. Boehnel, Proceedings of the Ist International Conference on Optical Sensors, London, 1983, pp. 96–99.

[41] K. Cherif, S. Hleli, A. Abdelghani, N. Jaffrezic-Renault, V. Matejec, Chemical detection in liquid

media with a refractometric sensor based on a multimode optical fiber, Sensors 2 (2002) 195–204.

[42] C. Ronot, M. Archenault, H. Gagnaire, J.P. Goure, N. Jaffrezic-Renault, T. Pichery, Detection of chemical vapours with a specifically coated opticalfiber sensor, Sens. Actuators B B11 (1993) 375–381.

[43] M. Archenault, H. Gagnaire, J.P. Goure, N. Jaffrezic-Renault, A simple intrinsic optical-fiber chemical sensor, Sens. Actuators B B8 (1992) 161–166.

[44] B.D. MacCraith, C. McDonagh, T. Buttler, Fibre-optic chemical sensors based on evanescent wave interactions in sol–gel-derived porous coatings, J. Sol–Gel Sci. Technol. 2 (1994) 661–665.

[45] Dr. S. Venkateswara Rao, S. Srinivasulu, Direct Contact Evanescent Wave Absorption Enabled Fiber Optic Refractive Index Sensor Operating in the Dynamic Range of 20ºC to 60ºC, Materials Today: Proceedings, Vol. No. 51, Part No. 1, (2022) 387-393.

[46] V. Matejec, I. Kasik, M. Somat, A. Abdelghani, N. Jaffrezic-Renault, M. Lacroix, Fabrication and properties of doped porous polysiloxane Sol–Gel layers on optical fibers, J. Sol–Gel Sci. Technol. 13 (1998) 569–573.

[47] M. Archenault, H. Gagnaire, J.P. Goure, N. Jaffrezic-Renault, A simple intrinsic optical fiber refractometer, Sens. Actuators B B5 (1991) 173–179.

[48] A. Abdelghani, J.M. Chovelon, N. Jaffrezic-Renault, M. Lacroix, H. Gagnaire, C. Veillas, B. Berkova, M. Chomat, V. Matejec, Optical fiber sensor coated with porous silica layers for gas and chemical vapour detection, Sens. Actuators B 44 (1997) 495–498.