# Evanescent Wave Absorption Based Fiber Optic Chemical Sensor – Determination of Various Parameters of Binary Liquids

**S. SRINIVASULU[1] & Dr. S. VENKATESWARA RAO[2]**

[1&2] *Department of Physics, JNTUH College of Engineering Hyderabad,*
*Hyderabad–500085, Telangana State, India.*

**ABSTRACT:** *A Novel optical fiber sensor capable of measuring the parameters such as Refractive Index, Density, Molar Volume, Molar Refraction and Dielectric Constant with more accuracy and high sensitivity has been reported in the present paper. Light launched from a source of 630nm travels through a U-shaped glass rod connected between a pair of PCS fibers of 200/230 µm diameters which is immersed in chemical mixtures, reaches the light detector. During the light transmission through the sensing zone, most of the light enters into the liquid surrounding the U-shaped glass rod, due to the evanescence of light into the liquid cladding, till the refractive index of liquid is increased upto the refractive index of the U-shaped glass core. Thus a relationship is formed between the light reaching the detector and the refractive index of liquid surrounding the U-shaped glass rod. This arrangement can, not only be used to sense the refractive index of unknown transparent liquids in the dynamic range of 1.35$n_D$ to 1.50$n_D$ but also be used to determine Density, Molar Volume, Molar Refraction and Dielectric Constant of binary liquid. The sensor so developed is highly versatile, simple, reliable and rugged.*

***KEYWORDS:*** *Density, Dielectric Constant, Evanescence, Molar Refraction, Molar Volume, Refractive Index, Sensitivity.*

## I. INTRODUCTION

The study of refractive indices and their predictions are important in the determination of compositions of various mixtures of liquids. The analysis of several parameters such as the measurement of refractive index in combination with melting point, boiling point, density and other chemical data are much useful industrially and also for substances that include serapes, oils and waxes etc. [1]. Optical fiber sensors based on different designs and with various geometrical constructions for wide range of industrial applications have been reported in the literature [2-5]. Using optical fiber technology it is possible to design several innovative fiber optic index of refraction transducers that exhibit unique properties. The role played by organic liquids are worth noting in several areas such as pharmaceuticals, biomedical sciences, chromatographic techniques, solvent system of refraction medium and solvent system in spectroscopy. The constitution of molecule and the internal structure of the molecule of any substance decide by the physical properties and hence the macroscopic behavior. To know the complete picture such as structure of the molecule ternary, binary mixture of liquids, it is needed to determine the properties of liquids like Refractive Index, Density, Molar Volume, Molar Refraction and Dielectric Constant etc. [6-9]. Optical fiber sensors have received much attention in recent past, due to the immunity to electromagnetic interference (EMI), their safety in explosive and hazardous environment, remote sensing of parameters, distributed sensing, offers high sensitivity and reliability. These features along with low cost, small in size, easy to installation makes the fiber optic system applicable for various industrial, engineering, medical, defense, biomedical, food, beverages and monitoring systems [10-15]. For the determination of compositional proportional presence of two liquids in a particular mixture M. Bali et al had introduced a novel sensor based on optical fibers [16-17]. The present sensor was developed to study the various parameters i.e. Refractive Index, Density, Molar Volume, Molar Refraction and Dielectric Constant of Benzene mixed with Methyl acetate by taking in different proportions.

## II. EXPERIMENTAL DETAILS

The basic components of experimental arrangement consist of mainly four parts.

1. Laser light source of 630nm wavelength radiation.
2. Bench mark light detector.
3. Pair of step index plastic clad silica (PCS) fibers.
4. U-shaped glass rod of following parameter.

| | |
|---|---|
| Thickness of rod: | 0.5mm |
| Total height of the glass rod(H): | 40m |
| Width between two prongs(Z): | 5mm |
| Radius of the Curvature(X): | 2.5mm |
| Depth of the Curvature(Y): | 2.5mm |

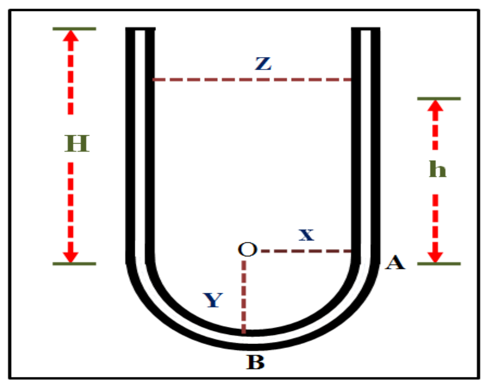



**Fig.1: Geometrical parameters of the U-shaped glass rod**

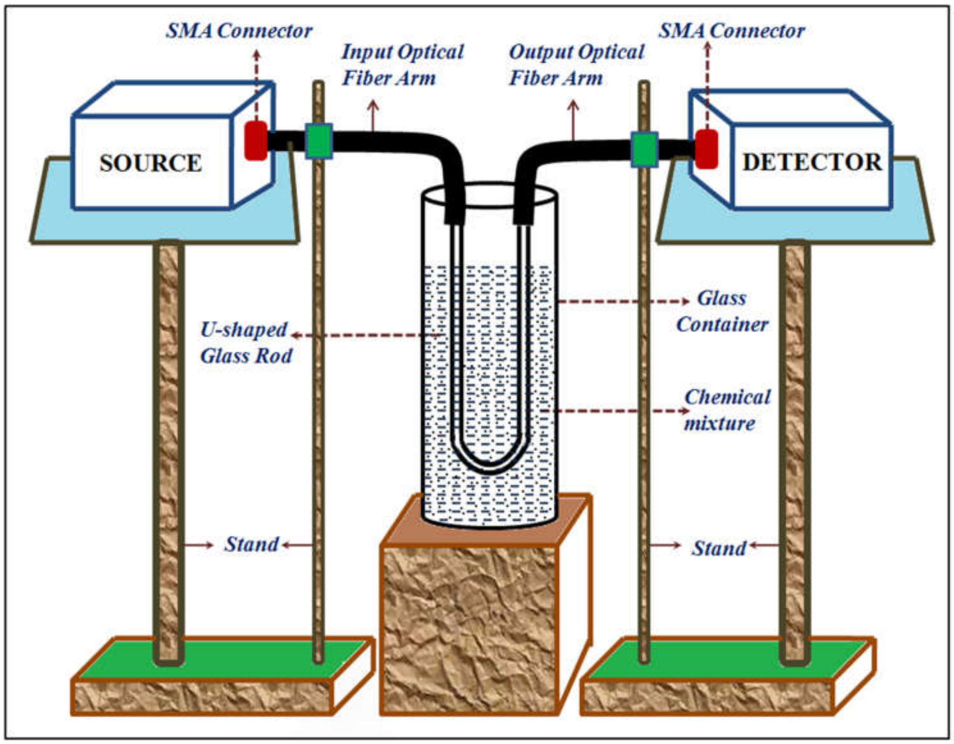



**Fig.2: Experimental arrangement of Fiber Optic Chemical Sensor**

In the experimental setup the light source and the detector are connected by a pair of PCS optical fibers of 200/230 µm diameters via a U-shaped glass rod of specific physical parameters by using necessary connectors and suitable adhesives. Benzene and Methyl acetate were selected in the present experimentation with an intension to have the dynamic range $1.35n_D$ to $1.50n_D$. The standard physical and chemical properties of the both chemical compounds were listed in table-1.

**Table-1: Standard physical and chemical parameter of Benzene and Methyl acetate**

| Chemical Parameters | Benzene ($C_6H_6$) | Methyl acetate ($C_3H_6O_2$) |
|---|---|---|
| Molar Mass (g/mole) | 78.11 | 74.08 |
| Refractive Index(n) | 1.5011 (20°C) | 1.3614 (20°C) |
| Density (g/ml) | 0.8756 | 0.9342 |
| Color | Colorless | Colorless |
| Boiling Point | 80.08°C | 56.7°C |
| Melting Point | 5.558°C | -98.2°C |
| Molar Volume (c.c./mole) | 89.2074 | 79.2978 |
| Molar Refraction (c.c./mole) | 26.2863 | 17.5618 |
| Dielectric Constant ($\varepsilon = n^2$) | 2.2533 | 1.8534 |

By mixing a known concentration of each liquid taken by burette system the binary mixtures were prepared and each mixture was stored in an air tight stopper glass bottle. The refractive indices of all the mixtures were determine by using Digital Refractometer (RX 7000i) and readings were recorded and tabulated in table-2. The sensor was calibrated by measuring the indices of refraction of the water that distilled twice. The measurement of masses were taken by using a Digital Balance AUX 220 series with an accuracy of $\pm$ $1\times10^{-4}$ gm. A suitable specific gravity bottle was used for the measurement of densities. While measuring the densities care was taken to measure the densities accurately by taking the average of the measurement of densities 3 times each. The above measured values can be used to determine the various parameters by using the following formulae and values are tabulated in table-2.

- The Molar Refraction of pure liquid

$$R_m = \frac{M}{\rho}\left[\frac{n^2-1}{n^2+2}\right] \quad (1)$$

- Molar Volume for binary chemical mixtures

$$V_{ms} = \frac{M_a X_a + M_b X_b}{\rho_{ms}} \quad (2)$$

- Molar Refraction for binary chemical mixtures

$$R_{ms} = \frac{M_a X_a + M_b X_b}{\rho_{ms}}\left[\frac{n^2-1}{n^2+2}\right] \quad (3)$$

**Where:**

$R_m$ → Molar Refraction of pure chemical

$V_{ms}$ → Molar Volume of binary chemical mixtures

$R_{ms}$ → Molar Refraction of binary chemical mixtures

$\rho_{ms}$ → Density of binary chemical mixtures

n → Refractive index of solution

$M_a$ & $M_b$ → Molar masses of 1st and 2nd pure chemical compounds

$X_a$ & $X_b$ → Molefracations of 1st and 2nd pure chemical compounds

Output Power when air surrounding the U-shaped glass rod: -33.8dBm

**Table-2:Molefraction of Benzene in Benzene + Methyl acetate mixtures, Molefraction of Methyl acetate in Benzene + Methyl acetate mixtures, Refractive Index, Output Power(dBm), Power Loss(dBm), Density(g/ml), Molar Volume(c.c./mole), Molar Refraction(c.c./mole) and Dielectric Constant ($\varepsilon = n^2$) of Benzene + Methyl acetate chemical mixtures.**

| S. No. | Volume of the binary mixtures | | Molefraction | | Refractive Index (R.I.) | Output Power (dBm) | Power Loss (dBm) | Density $\rho_{ms}$ (g/ml) | Molar Volume $V_{ms}$ (c.c./mole) | Molar Refraction $R_{ms}$ (c.c./mole) | Dielectric Constant ($\varepsilon = n^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Benzene (ml) | Methyl acetate (ml) | Benzene ($X_a$) | Methyl acetate ($X_b$) | | | | | | | |
| 1 | 10 | 0 | 1.0000 | 0.00000 | 1.49023 | -47.2 | 13.4 | 0.8649 | 90.3110 | 26.1195 | 2.2207 |
| 2 | 9 | 1 | 0.9101 | 0.0899 | 1.47612 | -46.2 | 12.4 | 0.8704 | 89.3241 | 25.1990 | 2.1789 |
| 3 | 8 | 2 | 0.8182 | 0.1818 | 1.46208 | -45.3 | 11.5 | 0.8770 | 88.2296 | 24.2596 | 2.1377 |
| 4 | 7 | 3 | 0.7241 | 0.2759 | 1.44798 | -44.2 | 10.5 | 0.8811 | 87.3886 | 23.3926 | 2.0966 |
| 5 | 6 | 4 | 0.6279 | 0.3721 | 1.43401 | -43.1 | 9.3 | 0.8890 | 86.1760 | 22.4426 | 2.0564 |
| 6 | 5 | 5 | 0.5294 | 0.4706 | 1.42032 | -42.0 | 8.2 | 0.8959 | 85.0692 | 21.5421 | 2.0173 |
| 7 | 4 | 6 | 0.4286 | 0.5714 | 1.40697 | -41.0 | 7.2 | 0.9027 | 83.9784 | 20.6717 | 1.9796 |
| 8 | 3 | 7 | 0.3253 | 0.6747 | 1.39578 | -40.4 | 6.6 | 0.9086 | 82.9749 | 19.9272 | 1.9482 |
| 9 | 2 | 8 | 0.2195 | 0.7805 | 1.38042 | -39.2 | 5.4 | 0.9204 | 81.4478 | 18.8855 | 1.9056 |
| 10 | 1 | 9 | 0.1111 | 0.8889 | 1.36901 | -38.3 | 4.5 | 0.9273 | 80.3707 | 18.1354 | 1.8742 |
| 11 | 0 | 10 | 0.0000 | 1.0000 | 1.35697 | -37.5 | 3.7 | 0.9324 | 79.4509 | 17.4025 | 1.8414 |

## III. RESULTS AND DISCUSSION

The light launched from the source transmits through the 1st fiber and enters into U-shaped glass rod will be coupled into the 2nd fiber and appears in the light detector connected at other end. The U-shaped glass rod acts as a core and binary liquid mixture that surrounds the glass rod acts as a cladding in the sensing zone. While light transmitting from 1st fiber to 2nd fiber it interacts with the binary mixture around the glass rod. This interaction leads to some amount of light enters into the liquid in the form of an evanescent wave. The amount of light that escapes into the liquid depends upon the refractive index of concentration of the liquid. More is the concentration of the binary mixture, more is the amount of the light that enters into the mixture, which results in the less amount of power that enters into the detector. By taking the constituents of the binary mixtures in different proportion, different solutions with different refractive indices were prepared and maintained around the glass rod and the relation between refractive index and output power reaching the detector were plotted in figure [fig.-3]. The relationship between the power loss vs refractive index was also plotted graphically [fig.-4].

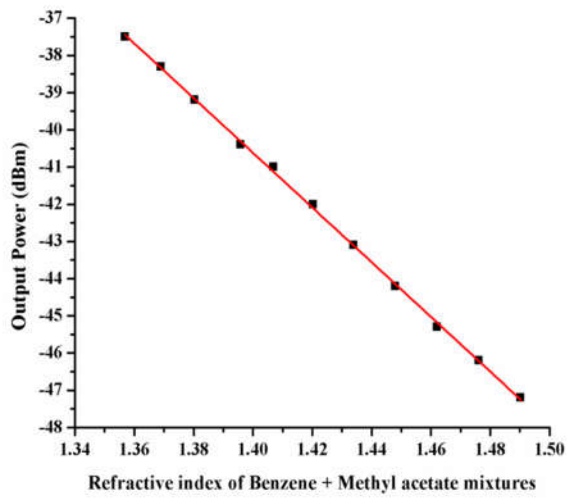



Fig.3: Relation between Refractive Index Vs Output Power (dBm) of Benzene + Methyl acetate mixtures

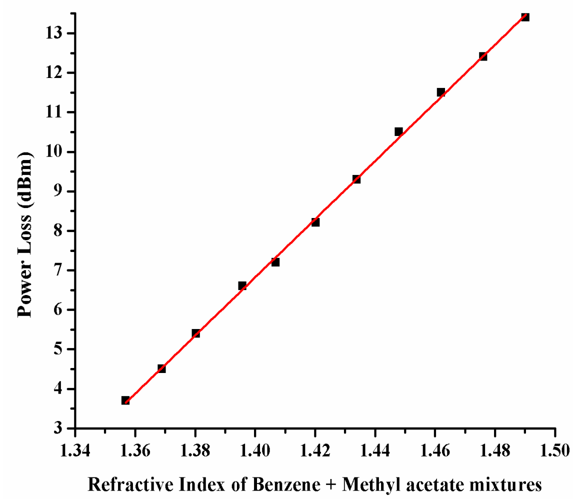



Fig.4: Relation between Refractive Index Vs Power Loss (dBm) of Benzene + Methyl acetate mixtures

From the data refractive index, output power and density obtained experimentally the other parameters such as Molar Volume, Molar Refraction, Dielectric Constant and Molefraction were calculated and the graphs were plotted between Density Vs Output Power [fig.-5], Density Vs Power Loss [fig.-6], Molar Volume Vs Output Power [fig.-7], Molar Volume Vs Power Loss [fig.-8], Molar Refraction Vs Output Power [fig.-9], Molar Refraction Vs Power Loss [fig.-10], Dielectric Constant Vs Output Power [fig.-11], Dielectric Constant Vs Power Loss [fig.-12], Molefractions of Benzene and Methyl acetate Vs Output Power [fig.-13], Molefractions of Benzene and Methyl acetate Vs Power Loss [fig.-14],

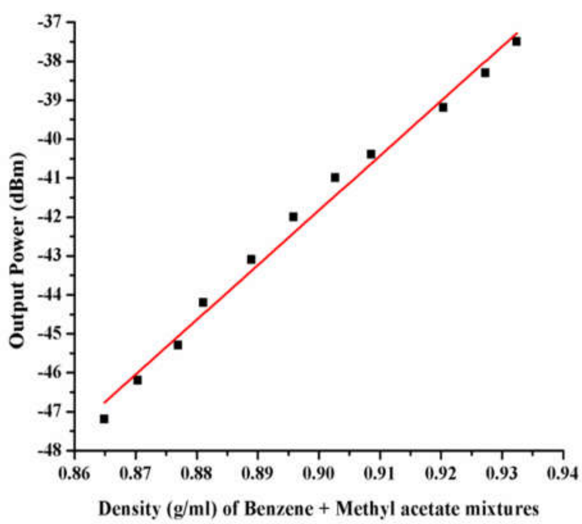



Fig.5: Relation between Density (g/ml) Vs Output Power (dBm) of Benzene + Methyl acetate mixtures

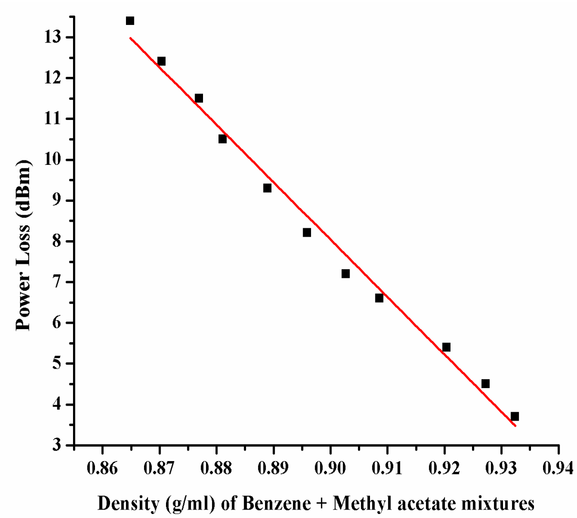



Fig.6: Relation between Density (g/ml) Vs Power Loss (dBm) of Benzene + Methyl acetate mixtures

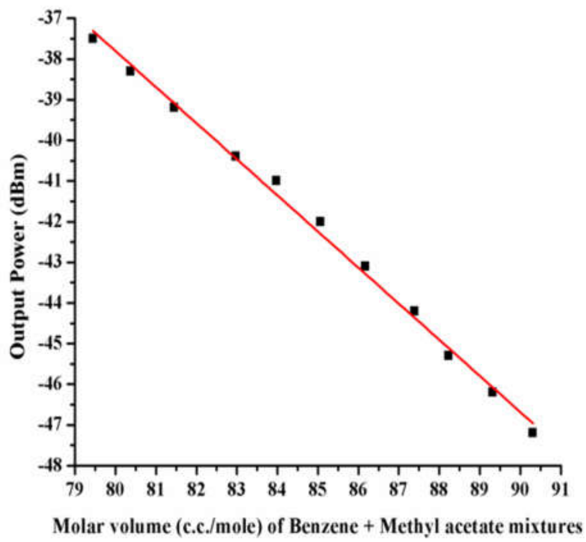



**Fig.7: Relation between Molar Volume (c.c./mole) Vs Output Power (dBm) of Benzene + Methyl acetate mixtures**

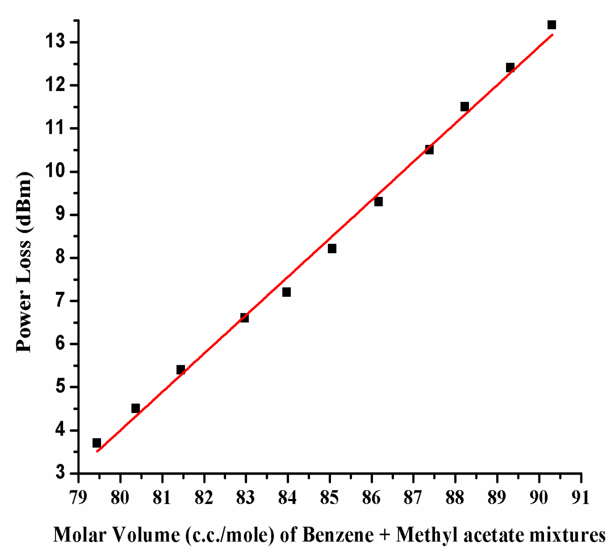



**Fig.8: Relation between Molar Volume (c.c./mole) Vs Power Loss (dBm) of Benzene + Methyl acetate mixtures**

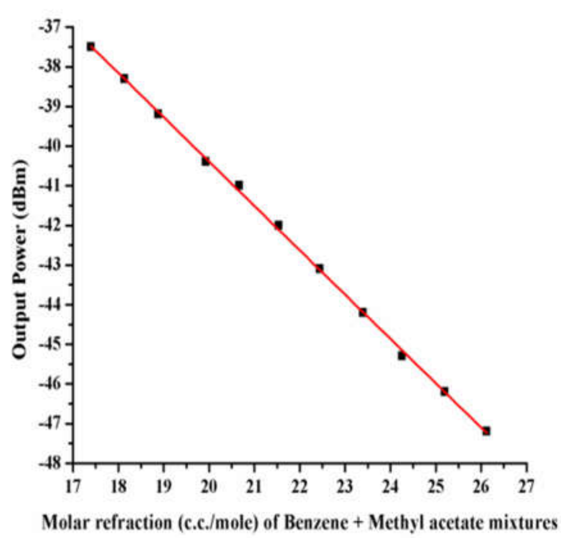



**Fig.9: Relation between Molar Refraction (c.c./mole) Vs Output Power (dBm) of Benzene + Methyl acetate mixtures**

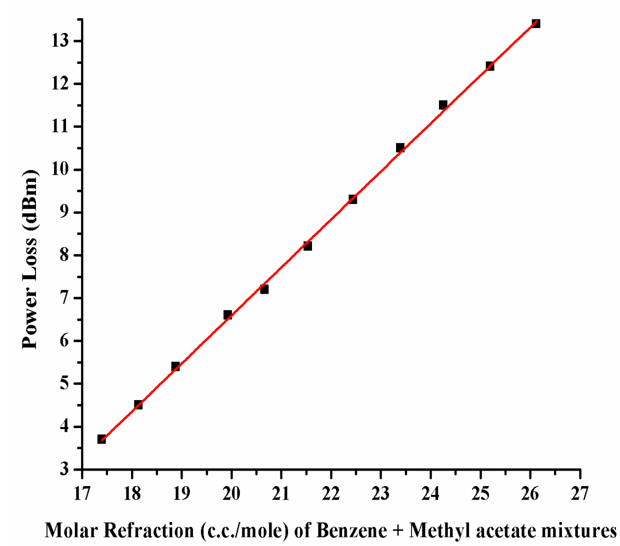
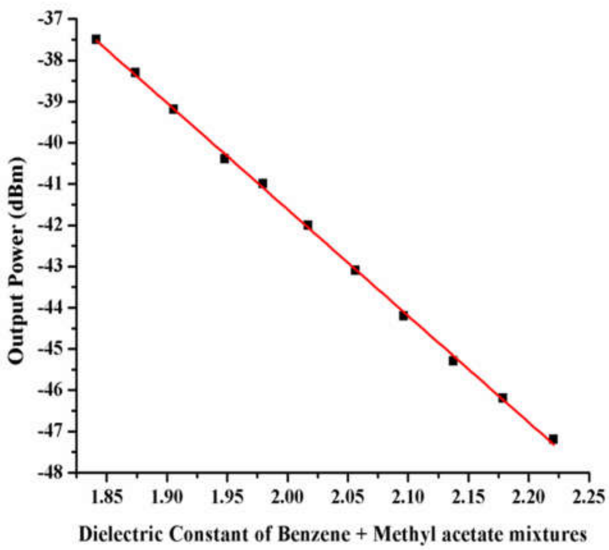



**Fig.10: Relation between Molar Refraction (c.c./mole) Vs Power Loss (dBm) of Benzene + Methyl acetate mixtures**



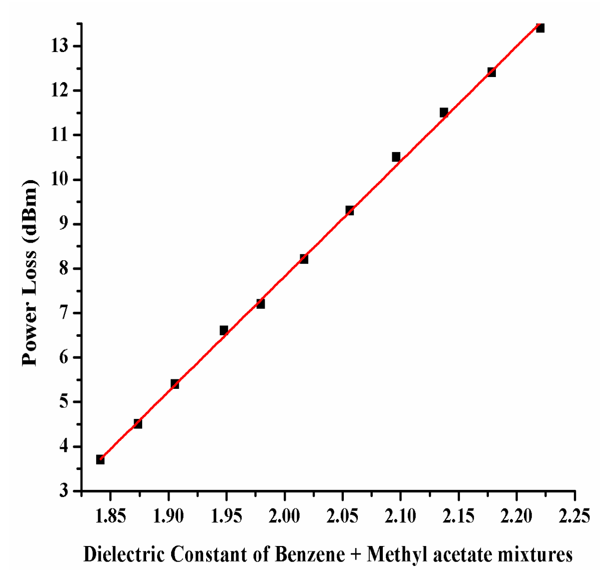
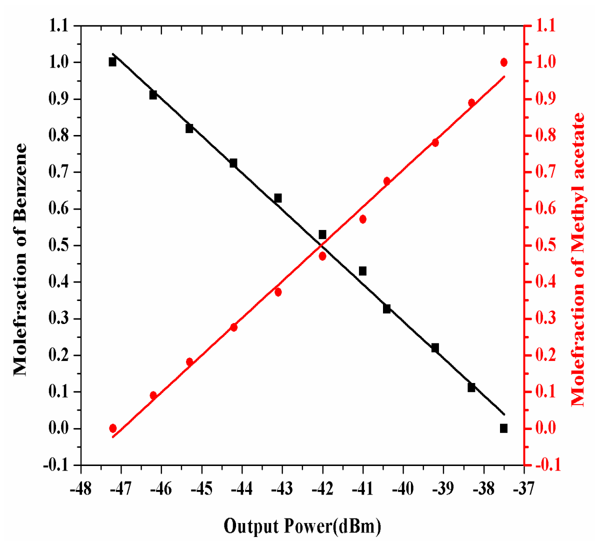




**Fig.11: Relation between Dielectric Constant ($\varepsilon_r$=n$^2$) Vs Output Power (dBm) of Benzene + Methyl acetate mixtures**

**Fig.12: Relation between Dielectric Constant ($\varepsilon_r$=n$^2$) Vs Power Loss (dBm) of Benzene + Methyl acetate mixtures**



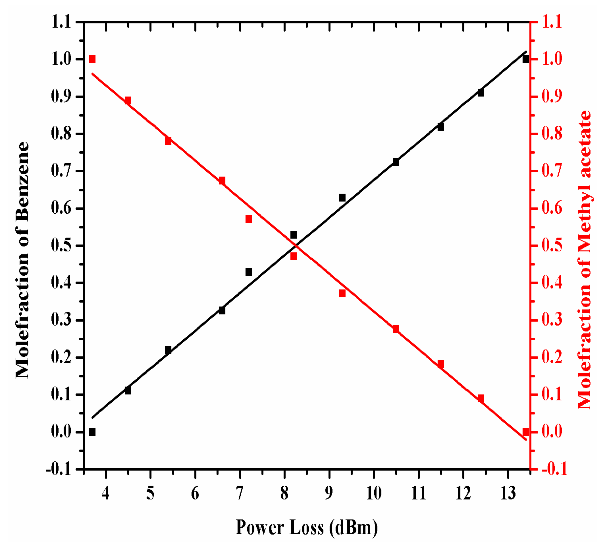




**Fig13: Relation between Output Power (dBm) Vs Molefractions of Benzene & Methyl acetate in Benzene + Methyl acetate mixtures**

**Fig.14: Relation between Power Loss (dBm) Vs Molefractions of Benzene & Methyl acetate in Benzene + Methyl acetate mixtures**

## IV. CONCULSION

The sensor developed can be used to measure the refractive index in the dynamical range i.e. operational range between 1.35$n_D$ to 1.50$n_D$ for the liquids either in transparent form or in dark form as the refractometer used in the experiment is capable of measuring the refractive index of both kinds of liquids at the room temperature (30℃). By obtaining the refractive index, output power and density data from experiment the other parameters such as Molar Volume, Molar Refraction and Dielectric Constant also can be determine with the help of the present sensor. Thus the sensor is set to be versatile device in measuring various parameters of the binary liquids both transparent and dark whose dynamic range is in between 1.35$n_D$ to 1.50$n_D$ at the room temperature.

## REFERENCES

[1] MReetaMehra, Application of refractive index mixing rules in binary systems of hexadecane and heptadecane with n-alkanols at differenttemperatures, Proc. Indian Acad. Sci. (Chem. Sci.), Vol. 115, No. 2, April 2003, pp. 147–154

[2] Jesenek, J.-Cermak: Optical Refractometer with Synthesized Coherence Function, In: Photonics, Devices and Systems, Proc. of SPIE, Vol.4016, 2000, pp. 204-210.

[3] Travica,S. et al.: Optically Powered Fiber Optic Temperature Thick Film NTC Sensor, Proc. of LASER 98, Tuscon, Arizona, USA, December 1998, pp. 562-567.

[4] G. A. Migani and A. A. Meneaglia, Direct and chemically mediated absorption spectroscopy using optical fiber instrumentation IEEE Sensors J. 252 – 7, 2002.

[5] Davis,Ch.M.-Carome, E.F.-Weik, M.H.-Ezekiel, S.-Einzing, R.E.: Fiber Optic Sensor Technology Handbook, Optical Technologies, Herndon, 1986.

[6] Turan, J.-Petrik,S.: Fiber Optic Sensors, Alfa, Bratislava, 1990.

[7] M. P. Wadekar, A. S. Shrirao and R. R. Tayade, Effect of change in concentration of solute and solvent on molar refraction and polarizability constant of some thiopyrimidine derivatives, Der PharmaChemica, 2014, 6(6), pp.90-96

[8] NeetuYadav, TanvirArfin and S.S. Yadava, Refractrometic Studies of Binary Mixtures of FlavouredCompounds and Some Hydrocarbons, Journal of Applied Solution Chemistry and Modeling, 2013, 2, pp. 68-76

[9] P.Krishnamurthi, T.Vasavi, Molecular Interactions Studies of Methanol and Ethanol in Non-PolarSolvent System, International journal of research in biomedical researchers, Vol 4(1) Jan- Mar 2013

[10] Javed Khan, MaqdoomFarooqui and S.H.Quadri, Verification of the molar refraction as an additive and constitutive property of binary liquid mixtures of water-ethanol and benzene-ethanol, Rasayan, Vol.4, No.4 (2011), pp. 944-946

[11] M Sheeba, M Rajesh, C P G Vallabhan, V P N Nampooriand P Radhakrishnan1-Fibre optic sensor for the detection of adulterant traces in coconut oil, Meas. Sci. Technol. 16 (2005), pp. 2247–2250

[12] Edited by Bishnu P. Pal, Fundamentals of Fiber Optics in Telecommunication and Sensor Systems, Second Reprint November 1997, Published by New age International (P) Limited, pp. 547-548

[13] MalathyBatumalay, SulaimanWadiHarun, Fauzan Ahmad, RoslanMd Nor,Nurul R. Zulkepely, and Harith Ahmad-Tapered Plastic Optical Fiber Coated WithGraphene for Uric Acid Detection, IEEE Sensors Journal, Vol. 14, No. 5, May 2014

[14] Nahla.A.Aljaber, Bushra.R.Mhdi, ShehabK.Ahmmad, Jamal.F.Hamode, Mohand. M.Azzawi, Abeer.H.Kalad, SuadM.AliDesign andConstruction Fiber sensor detection system for water nitrite pollution, IOSR Journal of Engineering (IOSRJEN),Vol. 4, Issue 02 (February. 2014), pp. 37-43

[15] PabitraNath - A novel fibre optic sensor probe withenhanced sensitivity, Current science, Vol. No. 4, 25 February 2011

[16] S. S. Patil, A. D. Shaligram-Refractometric fiber optic adulteration leveldetector for diesel, International Journal of Advances in Engineering & Technology, September 2011, Vol. No. 1, Issue 4, pp. 195-203

[17] L. M. Bali, AtulSrivastava, R. K. Shukla, and AnchalSrivastava (1999),"Optical sensor for determining adulteration in a liquid sample", Opt. Eng., Vol. 38, 1715 ; doi:10.1117/1.602223.