Cladding Mode Absorption Based Optical Fiber Intensity Modulated Sensor for the Measurement of Refractive Index of Optically Transparent Chemical Mixtures

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

[1&2] Department of Physics, JNTUH College of Engineering Hyderabad,
Hyderabad–500 085,Telangana State, India.

ABSTRACT: The study of refractive index of liquids play a major role in various applications such as industrial, defence, medical, food processing and consumer applications. In the present paper we report our latest results on a compact and low cost cladding mode absorption based U-shaped intensity modulated fiber optic sensor to sense the refractive indices of Acetone mixed in Benzene and Ethanol mixed in Benzene. The solid U-shaped glass sensor was prepared by bending the radius of a borosilicate glass rod to 1.0cm through a heating process. After which the U-shaped glass rod was connected to a light source of 630nm via the input fiber leg and a Bench mark power meter via the output fiber leg by using suitable adhesives. The experiment was carried out by exposing the U-shaped glass rod to the various concentrations of chemical mixtures. The results obtain through the experiment showed that a linear relationship was formed between refractive index of the different chemical concentrations with the power loss at the sensing zone. A dynamic range of 1.35n_D to 1.50n_D refractive index was obtained by using this sensor at room temperature.

Keywords: Borosilicate glass rod, Chemical concentrations, Cladding mode absorption, Dynamic range, Sensing zone.

I. INTRODUCTION

Optical fiber refractive index sensors based on cladding mode absorption have been the subject of research for the last few decades. The measurements of refractive index along with other parameters of liquids, oils, waxes, sugar serapes, fragrants, chemicals etc are very useful in many applications [1]. The internal structure or the geometry of the molecule, binary, ternary mixtures of liquids will determine the properties of index of refraction, polarization, density, molar volume, molar refraction, boiling point, melting point and other analytical behavior [2-8]. In the recent years the fiber optic sensors became more popular because they are safety in explosive and hazardous environment, immunity to electromagnetic interference, high sensitivity, remote sensing, distributed sensing and sensing at inaccessible areas etc. Because of many useful features of fiber optic sensors such as low in cost, miniature in size, intrinsic safety and ease of installation make the system ideal for various applications like inline chemical processing, food processing beverages, medical analysis etc. For the determination of ratio of compositions of binary liquids in a mixture an optical sensor was developed by L.M. Bali et al [9]. Sensors for PH measurements, refractive index study, to determine the organic pollutants in the water were developed with various sensor designs and with different sensing method and reported in the literature [10-15]. In the present paper extrinsic intensity modulated fiber optic U-shaped glass probe cladding mode absorption based sensor was developed to determine the refractive index of the chemical concentration of Acetone mixed in Benzene and Ethanol mixed in Benzene.

II. EXPERIMENTAL DETAILS

The experimental setup consists of three basic components. The light source of 630nm wavelength, a suitable Bench mark optical power meter of suitable range and a sensing system consisting of a U-shaped glass probe of thickness 0.2cm, total height of the glass rod 3.0cm, height of the glass rod immersed in the liquid 2.0cm, width between the two prongs 1.5cm and depth of the curvature 1.0cm. One of the ends of the glass rod is connected to the input fiber leg (200/230µm), and the other end of the glass rod is connected to the output fiber leg (200/230µm) by using suitable connecting adhesives. The second end of the input fiber leg is connected to light source of 630nm wavelength. The other end of the output fiber leg is connected to a Bench mark power meter. The experimental setup is shown in Fig.[1].

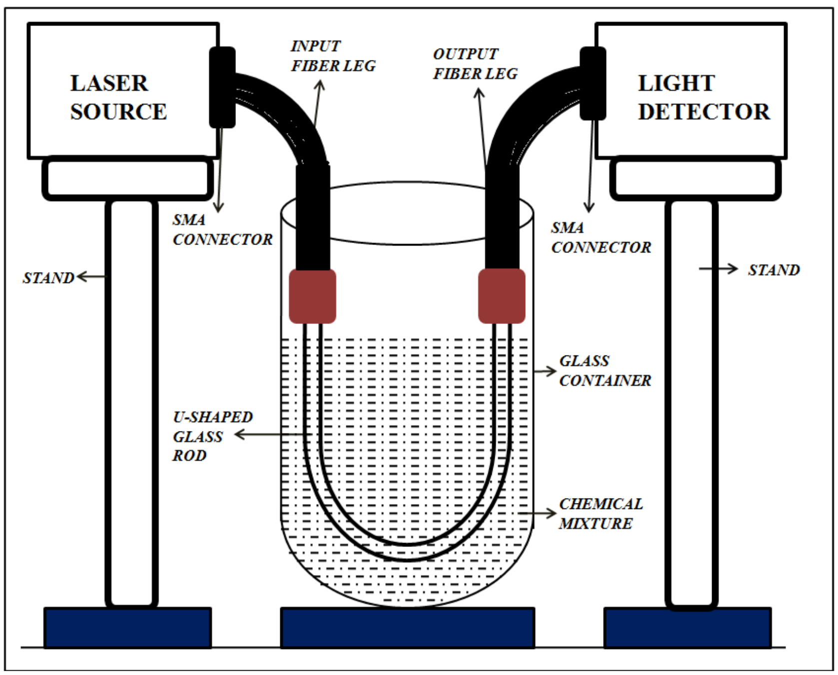

Fig.1: Experimental setup of Cladding Mode Absorption Based Optical Fiber Intensity Modulated Sensor.

Initially a binary mixture of Acetone mixed in Benzene was prepared by taking the known volumes of each liquid with proportional ratios making the total volume of the binary mixture equal to 10ml and preserved in an air tight stopper glass bottles. By using Abbe's refractometer in combination with sodium vapour lamp the refractive indices of all the mixtures were measured with an accuracy of 0.001 units and were recorded.

The U-shaped glass probe connected with light source and a power meter at the both ends by using 200/230μm PCS fibers was immersed in a glass container consist of a particular ratio of binary mixture. Light launched from the source transmits through the input fiber leg and enters into the U-shaped glass rod and couples out into the output fiber leg and enters into the power meter. Power observed in the power meter was recorded. Next the binary mixture with other ratio was exposed to the glass rod and output power was recorded. Finally the output was recorded by immersing U-shaped glass rod in all other binary chemical mixtures with different volume ratios and output power values are tabulated.

By using a specific gravity bottle the densities of all the binary mixtures with different ratios of volumes were measured. By using the suitable mathematical equations the molefraction, molar volume, molar refraction, polarization are determined and tabulated in tabular form 1.

Standard chemical parameter of Acetone and Benzene.

	Benzene	**Acetone**
Molar Mass (g/mole)	78.11	58.08
Refractive Index(n)	1.4957	1.3509
Density (g/ml)	0.8765	0.7846
Molar Volume (c.c./mole)	89.1158	75.1455
Molar Refraction (c.c./mole)	25.6753	16.2070
Polarization ($\varepsilon = n^2$)	2.2371	1.8249

Table-1: Molefraction of Benzene in Benzene + Acetone mixtures, Molefraction of Acetone in Benzene + Acetone mixtures and Refractive Index, Output Power(dBm), Density(g/ml), Molar Volume(c.c./mole), Molar Refraction(c.c./mole) and Polarization ($\varepsilon = n^2$) of Benzene + Acetone chemical mixtures.

S. No.	Volume of the binary mixtures (ml)		Molefraction		Refractive Index	Output Power (dBm)	Density (g/ml)	Molar Volume (c.c./mole)	Molar Refraction (c.c./mole)	Polarization ($\varepsilon = n^2$)
	Benzene	Acetone	Benzene	Acetone						
1	10	0	1.0000	0.0000	1.488	-48.73	0.8765	89.1158	25.6753	2.2141
2	9	1	0.9155	0.0845	1.451	-44.87	0.8673	88.1096	23.7240	2.1054
3	8	2	0.8280	0.1720	1.440	-44.10	0.8581	87.0118	22.9320	2.0736
4	7	3	0.7374	0.2626	1.433	-42.67	0.8489	85.8171	22.3038	2.0535
5	6	4	0.6436	0.3564	1.421	-41.10	0.8397	84.5198	21.4328	2.0192
6	5	5	0.5462	0.4538	1.414	-39.95	0.8305	83.1070	20.7674	1.9994
7	4	6	0.4452	0.5548	1.407	-39.42	0.8213	81.5748	20.0801	1.9796
8	3	7	0.3403	0.6597	1.389	-37.81	0.8121	79.9116	18.8995	1.9293
9	2	8	0.2313	0.7687	1.378	-36.23	0.8029	78.1080	18.0080	1.8989
10	1	9	0.1180	0.8820	1.362	-35.58	0.7937	76.0774	16.8732	1.8550
11	0	10	0.0000	1.0000	1.351	-33.28	0.7845	75.1455	16.2070	1.8252

To conform the values obtained and to ascertain the chemical behaviors of binary mixtures another combination of chemicals; Ethanol and Benzene mixtures were taken and the experimentation was repeated and results are tabulated in tabular form 2.

Standard chemical parameter of Ethanol and Benzene.

	Benzene	**Ethanol**
Molar Mass (g/mole)	78.11	46.07
Refractive index(n)	1.4957	1.3602
Density (g/ml)	0.8765	0.7895
Molar Volume (c.c./mole)	89.1158	58.6729
Molar Refraction (c.c./mole)	25.6753	12.9558
Polarization ($\varepsilon = n^2$)	2.2371	1.8501

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

S. No.	Volume of the binary mixtures (ml)		Molefraction		Refractive Index	Output Power (dBm)	Density (g/ml)	Molar Volume (c.c./mole)	Molar Refraction (c.c./mole)	Polarization ($\varepsilon = n^2$)
	Benzene	Ethanol	Benzene	Ethanol						
1	10	0	1.0000	0.0000	1.488	-48.73	0.8765	89.1158	25.6753	2.2141
2	9	1	0.9322	0.0678	1.460	-46.10	0.8678	87.5060	25.2108	2.1316
3	8	2	0.8593	0.1407	1.451	-45.25	0.8591	85.6733	23.4650	2.1054
4	7	3	0.7808	0.2192	1.443	-44.36	0.8503	83.6021	22.1631	2.0822
5	6	4	0.6961	0.3039	1.430	-42.30	0.8416	81.2417	20.9868	2.0449
6	5	5	0.6042	0.3958	1.422	-41.14	0.8329	78.5551	19.9625	2.0221
7	4	6	0.5044	0.4956	1.409	-39.53	0.8242	75.5047	18.6680	1.9853
8	3	7	0.3955	0.6045	1.396	-38.46	0.8155	72.0317	17.3074	1.9488
9	2	8	0.2762	0.7238	1.382	-36.47	0.8067	68.0791	15.8432	1.9099
10	1	9	0.1450	0.8550	1.370	-34.68	0.7980	63.5536	14.3749	1.8769
11	0	10	0.0000	1.0000	1.360	-34.12	0.7893	58.6729	12.9558	1.8496

III. RESULTS AND DISCUSSIONS

The tabulated experimental details of Acetone mixed in Benzene especially the variation of output power with refractive index shows a linear relationship. This relationship indicates as the refractive index of the binary mixture surrounding the U-shaped glass rod decreases the output power increases and vice-versa, which has been shown in Fig.[2].

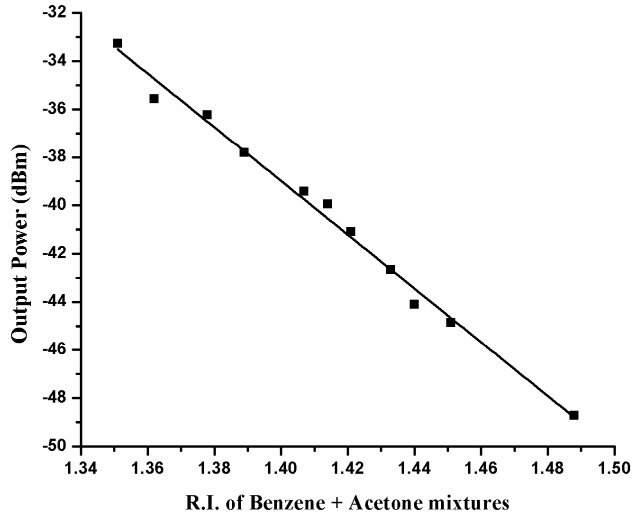

Fig-2: Relation between Refractive Index of Benzene + Acetone mixtures Vs Output Power (dBm)

In addition to variation of output power with refractive index of binary mixtures the other relations i.e. output power Vs density, output power Vs molefraction, output power Vs polarization, output power Vs molar volume and output power Vs molar refraction were determined and results are plotted in graphs [Fig.3-7].

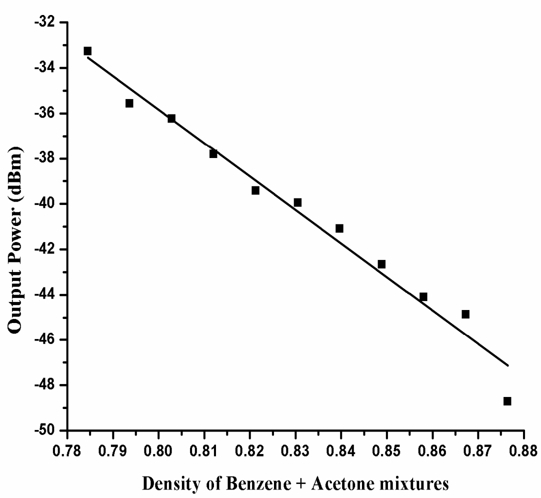

Fig-3: Relation between Density (g/ml) of Benzene + Acetone mixtures Vs Output Power (dBm).

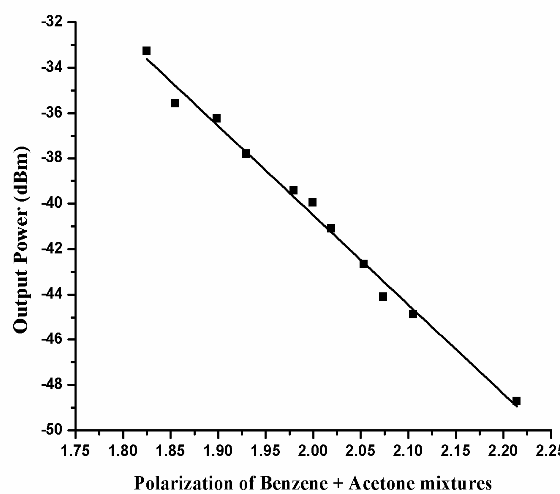

Fig-4: Relation between Polarization of Benzene + Acetone mixtures Vs Output Power (dBm).

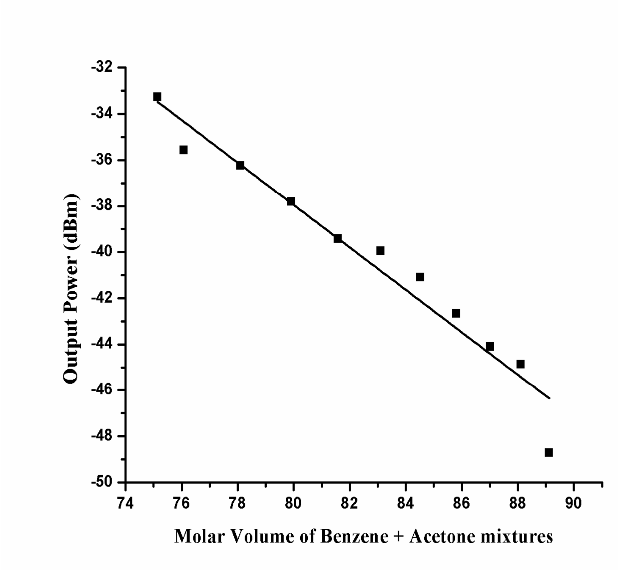

Fig-5: Relation between Molar Volume (c.c./mole) of Benzene + Acetone mixtures Vs Output Power (dBm).

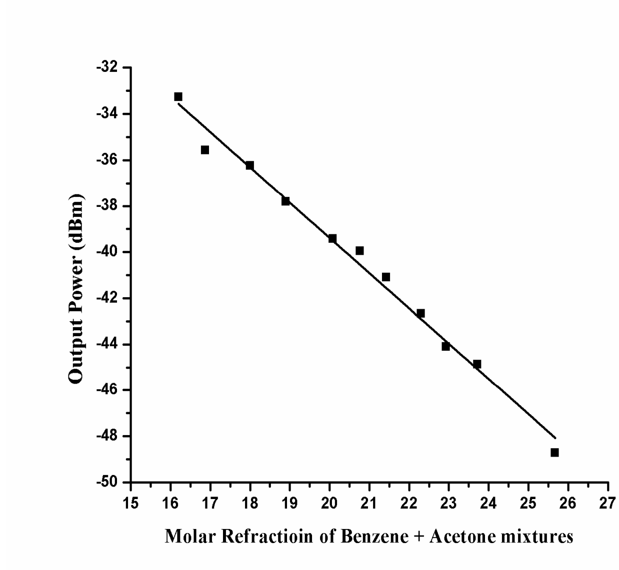

Fig-6: Relation between Molar Refraction of Benzene + Acetone mixtures Vs Output Power (dBm).

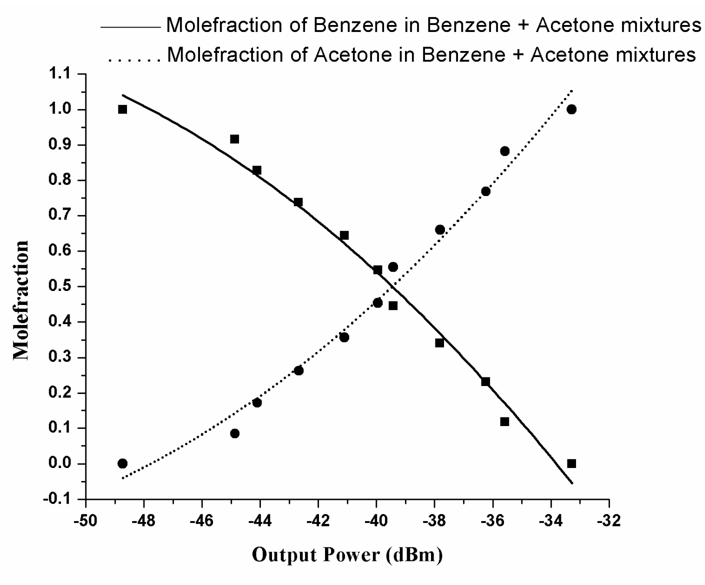

Fig-7: Relation between Molefraction of Benzene & Acetone in Benzene + Acetone mixtures Vs Output Power (dBm)

In conformation to the variation of output power with refractive index as tabulated in tabular form 2 the variation in the values of output power with refractive index of binary mixture of Ethanol mixed in Benzene forms a linear relationship and the results are plotted in graph [Fig.8].

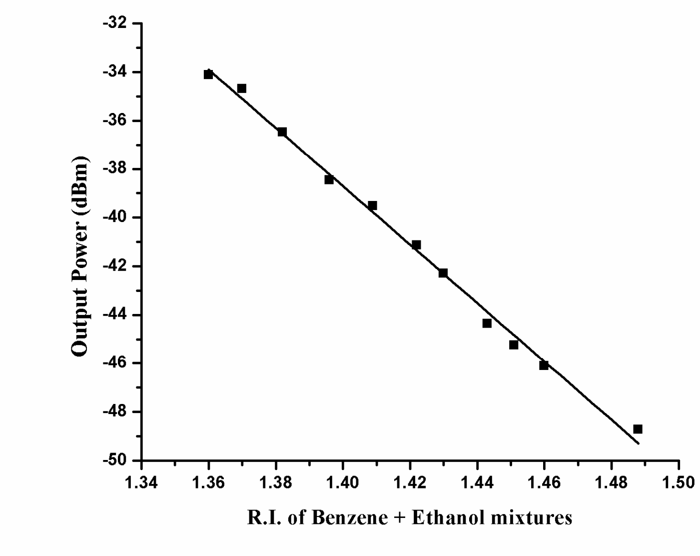

Fig-8: Relation between Refractive Index of Benzene + Ethanol mixtures Vs Output Power (dBm)

In addition to variation of output power with refractive index of binary mixtures the other relations i.e. output power Vs density, output power Vs molefraction, output power Vs polarization, output power Vs molar volume and output power Vs molar refraction were determined and results are plotted in graphs [Fig.9-13].

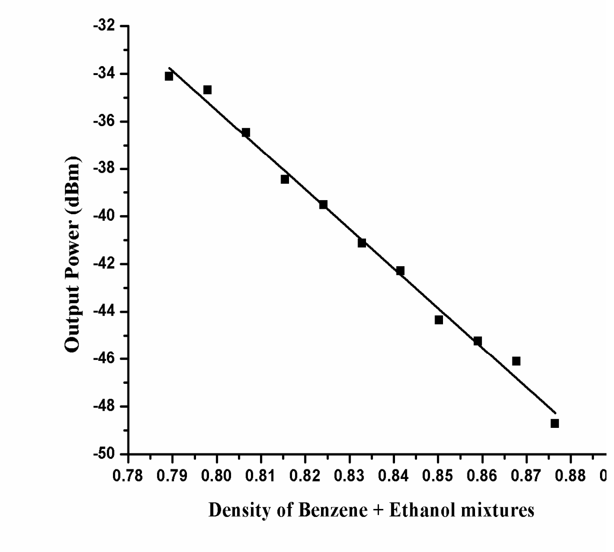

Fig-9: Relation between Density (g/ml) of Benzene + Ethanol mixtures Vs Output Power (dBm).

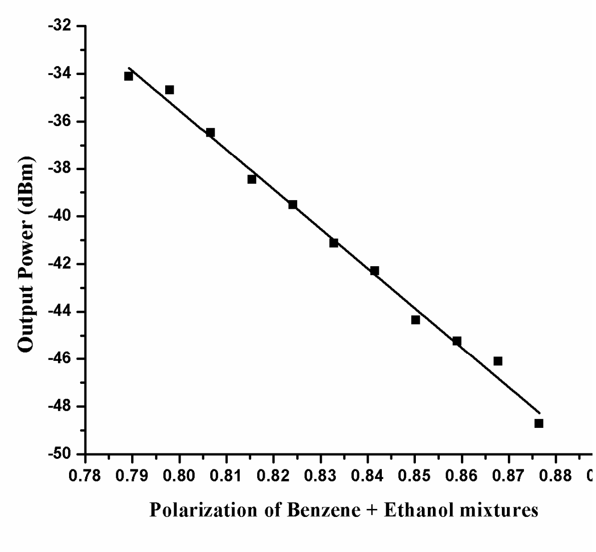

Fig-10: Relation between Polarization of Benzene + Ethanol mixtures Vs Output Power (dBm).

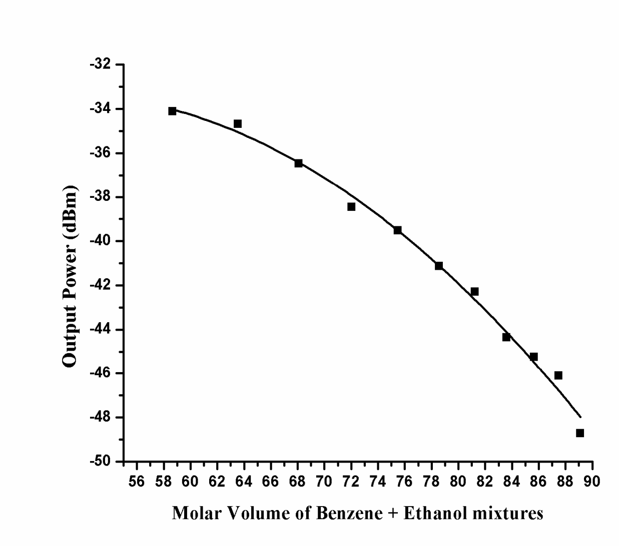

Fig-11: Relation between Molar Volume (c.c./mole) of Benzene + Ethanol mixtures Vs Output Power (dBm).

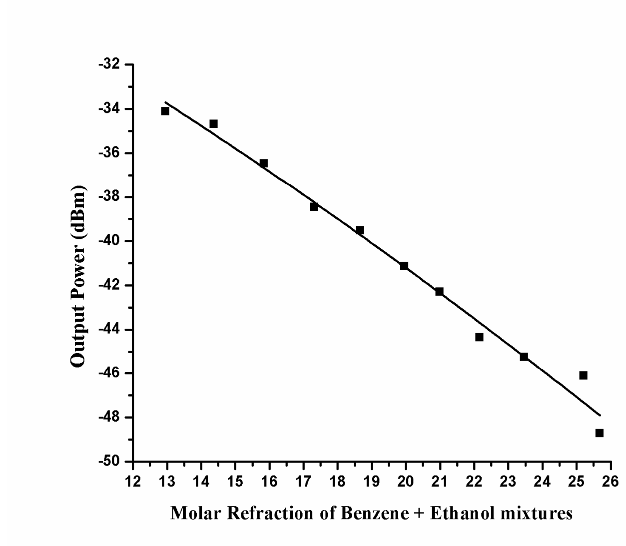

Fig-12: Relation between Molar Refraction of Benzene + Ethanol mixtures Vs Output Power (dBm).

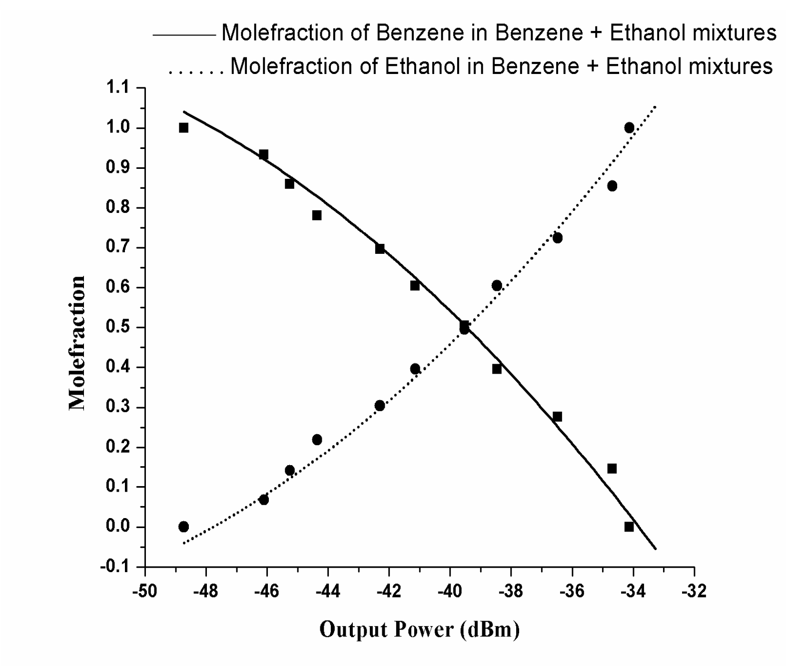

Fig-13: Relation between Molefraction of Benzene & Ethanol in Benzene + Ethanol mixtures Vs Output Power (dBm)

IV. CONCULSIONS

The refractive index of binary chemical mixtures of transparent liquids were determine with the help of existing Abbe's refractometer, corresponding powers are noted down and with the help of both these values (Refractive index & Output power) graphs (Fig. 2&8) are drown which can be used to measure the refractive index of unknown liquids in the dynamic range of 1.35n_D to 1.50n_D in the case of Acetone mixed in Benzene and 1.36n_D to 1.50n_D in the case of Ethanol mixed in Benzene at room temperature. This work also can be extended to design a refractive index sensor to record the refractive indices of both transparent and dark liquids at various temperatures.

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