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# Leaky Radiation Mode Based Intensity Modulated Extrinsic PCS Fiber Refractometer Operating at the Dynamic Range of 20ºC to 60ºC

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***ABSTRACT***

*The loss of light radiation from optical fibers can be exploited to construct various kinds of sensors, with different geometries to measure several environmental parameters such as pressure, temperature, liquid level, liquid refractive index, liquid pH, antibodies, electric current, rotation, displacement, acceleration, acoustic, electric and magnetic fields, etc. In the present paper a refractive index sensor operating at the dynamic temperature range of 20ºC to 60ºC based on the process of leaky radiation at the region of sensing is described. A sensing zone is created in the sensor by joining a U-shaped glass rod having dimensions compatible with the fibers was used, between a light source operating at the wavelength of 660nm and a benchmark optical power meter. Light transmitting through the optical fiber was observed to be leaked in the form of leaky radiation, when the U-shaped glass rod immersed into a liquid mixture of refractive index less than the refractive index of the glass rod. The amount of leaky radiation modes of transmitted light is directly related to the refractive index of liquid mixture into which the glass probe is immersed. The variation of light reaching the detector was found to change as well with temperature of the liquid mixture, when maintained at different temperatures. The work was carried by varying the length of sensing zone by increasing the depth of immersion of U-shaped glass rod into the liquid mixture prepared with the combination of Toluene and Acetic acid, taking at different proportion, making the total volume is equivalent to 20ml.*

***Keywords:*** *Acetic acid, Depth of immersion, Leaky radiation, Refractive index sensor, Sensing zone, Toluene, Wavelength of 660nm*

## INTRODUCTION

Optical fiber refractive index sensors are widely used in many applications like in the field of chemical, biological, medical, defence, food processing, pharmaceutical, agriculture, science and technology and even in consumer sector, as they have found many advantages over the traditional sensors, in the last few decades. The miniaturized size and light in weight makes them to be sued in various applications with ease and comfort comparing with other types of sensors. The raw material for the fabrication of optical fiber is sand, which is abundantly available across the globe, thereby they become cost effective. In FOS, the measured signal can be carried through optical fibers, they can be used to sense the measurands lying at far off distances, simply keeping the source and detector on the desktop in front of us, using remote sensing technique. These sensors also can be used to detect measurands from otherwise inaccessible region, as their size is equivalent to the size of human hair. It is highly difficult to measure the physical quantities from the region where the radiation field exists, but as the optical fibers are immune to radio activity, they can be used to measure the parameters that are present in radiation field, simply by sending the sensor head into the radiation zone. The chemical inertness of optical fibers helps them to monitor the chemical process on the real time basis. It is possible to multiplex a large number of sensors in a single fiber optic network for continuous measurement of various parameters along fiber length in terms of



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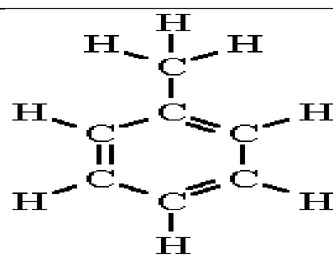
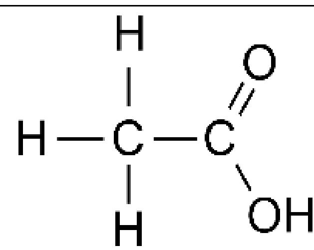
distributed sensing due to their large bandwidth. Thus, the optical fiber implementation extended from telecommunication to sensing applications and as a result an intensive R&D activity picked up around the world leading to the emergence of various kinds of optical fiber sensors and devices. The important feature of FO sensors is, its construction based on the parameter to be measured. Several kinds of geometries have been proposed across the globe in measuring resonance sensors [1-3], fiber optic interferometric sensors [4-7], intensity modulated sensors [8, 9], spectrally based FO sensors [10-16] and sensors based on photonic crystal [17-19]. Optical fibers with metal cladding exhibit high attenuations at optical wavelengths and if length of metal cladding is longer, the larger will the attenuation. This fact was made use in the construction of a fiber optic thermometer [41]. In the other design of the sensor a plastic clad silica fiber was used to construct a thermometer especially for application in medical field by exploiting the intensity induced modulation due to thermo sensitive cladding around a bare portion of the sensor [42].

## EXPERIMENTAL DETAILS

The design and development of the present sensor was taken up keeping the parameter into consideration i.e. refractive index of various liquids. The temperature dependent refractive index was intended to be investigated employing a U-shaped uniform solid glass rod made with a borosilicate glass and sensor operating at the wavelength of 660nm. Using proper connectorization, U-shaped glass probe having particular geometrical features was connected between a light transmitter and a light detector, using two insensitive PCS fibers of 200/230μm diameters, in which one is used as input fiber leg which connects the transmitter and the glass rod and the other fiber leg connects the glass rod and the optical detector.

In order to study the refractive index of liquids of various refractive index values lying within a specific range, two chemicals have been chosen i.e. Toluene and Acetic acid and their mixtures are prepared with taking the individual liquids at different proportions (20:0, 18:2, 16:4, 14:6, 12:8, 10:10, 8:12, 6:14, 4:16, 2:18, 0:20) making the total volume equivalent to 20ml.

**Properties of Toluene and Acetic acid:**

| **Properties** | **Toluene ($C_7H_8$)** | **Acetic acid ($CH_3COOH$)** |
|---|---|---|
| Structure |   |   |
| Refractive index | 1.4967 at 20$^{o}$C | 1.3716 at 20$^{o}$C |
| Melting point | -94.9$^{o}$C | 16.6$^{o}$C |
| Boiling point | 110.6$^{o}$C | 117.9$^{o}$C |

Taking a small drop of liquid from each mixture, the refractive index of all the mixtures were determined using automatic digital refractometer of modal number RX-7000i (Atago make, Japan) at temperature range starting from 20$^{o}$C to 60$^{o}$C, at the wavelength of 5893Å (sodium light) and data was recorded in tabular form along with mole fraction of Acetic acid in Toluene + Acetic acid mixture [table-1].

**Table.1:** Mole fraction of Acetic acid in Toluene + Acetic acid chemical mixture and Refractive indices of mixtures at various temperatures (from 20$^{o}$C to 60$^{o}$C).



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| S. No. | Mole fraction of Acetic acid in mixture | Refractive Index at various temperatures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20°C | 25°C | 30°C | 35°C | 40°C | 45°C | 50°C | 55°C | 60°C |
| 1 | 0.00000 | 1.50171 | 1.49770 | 1.49325 | 1.48974 | 1.48582 | 1.48293 | 1.47795 | 1.47509 | 1.47102 |
| 2 | 0.16947 | 1.47995 | 1.47782 | 1.47409 | 1.47122 | 1.46808 | 1.46508 | 1.46201 | 1.45723 | 1.45481 |
| 3 | 0.31465 | 1.46327 | 1.46072 | 1.45723 | 1.45468 | 1.45128 | 1.4483 | 1.44505 | 1.44102 | 1.43823 |
| 4 | 0.44042 | 1.44726 | 1.44492 | 1.44129 | 1.43823 | 1.43502 | 1.43282 | 1.42968 | 1.42607 | 1.42382 |
| 5 | 0.55042 | 1.43407 | 1.43123 | 1.42873 | 1.42511 | 1.42202 | 1.41978 | 1.41672 | 1.41348 | 1.41021 |
| 6 | 0.64744 | 1.42145 | 1.41978 | 1.41605 | 1.41348 | 1.41021 | 1.40781 | 1.40403 | 1.40131 | 1.39807 |
| 7 | 0.73366 | 1.41125 | 1.40821 | 1.40547 | 1.40228 | 1.39983 | 1.39621 | 1.39307 | 1.39012 | 1.38798 |
| 8 | 0.81078 | 1.40182 | 1.39807 | 1.39512 | 1.39229 | 1.38921 | 1.3863 | 1.38368 | 1.38073 | 1.37702 |
| 9 | 0.88018 | 1.39137 | 1.38821 | 1.38584 | 1.38254 | 1.37952 | 1.37607 | 1.37372 | 1.37048 | 1.36775 |
| 10 | 0.94295 | 1.38368 | 1.38064 | 1.37757 | 1.37472 | 1.37116 | 1.36873 | 1.36502 | 1.36272 | 1.35976 |
| 11 | 1.00000 | 1.37757 | 1.37498 | 1.37129 | 1.36802 | 1.36561 | 1.36292 | 1.35976 | 1.35608 | 1.35312 |

Maintaining each liquid surrounding the U-shaped glass rod with an immersion depth of 1cm and rising the liquid temperature from 20°C to 60°C using a temperature bath, the variation in output power reaching the detector was recorded and tabulated [table-2].

**Table.2:** Mole fraction of Acetic acid in Toluene + Acetic acid chemical mixture and Output power at various temperatures (from 20°C to 60°C) for the operating wavelength of the source 660nm and depth of immersion is 1cm.

| S. No. | Mole fraction of Acetic acid in mixture | Output Power (dBm) at various temperatures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20°C | 25°C | 30°C | 35°C | 40°C | 45°C | 50°C | 55°C | 60°C |
| 1 | 0.00000 | -39.00 | -38.70 | -38.33 | -38 | -37.63 | -37.37 | -36.90 | -36.63 | -36.30 |
| 2 | 0.16947 | -37.13 | -36.83 | -36.50 | -36.33 | -36.17 | -36.03 | -35.90 | -35.73 | -35.53 |
| 3 | 0.31465 | -35.97 | -35.87 | -35.73 | -35.50 | -35.23 | -35.00 | -34.80 | -34.60 | -34.47 |
| 4 | 0.44042 | -34.90 | -34.70 | -34.63 | -34.47 | -34.17 | -33.87 | -33.63 | -33.33 | -33.13 |
| 5 | 0.55042 | -34.03 | -33.73 | -33.57 | -33.27 | -33.07 | -32.93 | -32.80 | -32.50 | -32.30 |
| 6 | 0.64744 | -33.00 | -32.93 | -32.73 | -32.50 | -32.30 | -32.10 | -31.77 | -31.57 | -31.43 |
| 7 | 0.73366 | -32.40 | -32.20 | -31.90 | -31.70 | -31.50 | -31.30 | -31.13 | -30.87 | -30.70 |
| 8 | 0.81078 | -31.63 | -31.43 | -31.23 | -31.07 | -30.80 | -30.57 | -30.37 | -30.03 | -29.60 |
| 9 | 0.88018 | -30.97 | -30.73 | -30.53 | -30.20 | -29.90 | -29.50 | -29.23 | -28.90 | -28.53 |



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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.94295 | -30.37 | -30.00 | -29.70 | -29.33 | -29.00 | -28.80 | -28.30 | -28.10 | -27.83 |
| 11 | 1.00000 | -29.70 | -29.4 | -29.13 | -28.67 | -28.40 | -28.20 | -27.83 | -27.50 | -27.30 |

The above method was repeated by increasing the depth of immersion of glass rod into liquid to 2cm and 3cm, the output power data at various temperatures were noted and tabulated [table 3& 4]

**Table.3** Mole fraction of Acetic acid in Toluene + Acetic acid chemical mixture and Output power at various temperatures (from 20$^o$C to 60$^o$C) for the operating wavelength of the source 660nm and depth of immersion is 2cm.

| S. No. | Mole fraction of Acetic acid in mixture | Output Power (dBm) at various temperatures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20$^o$C | 25$^o$C | 30$^o$C | 35$^o$C | 40$^o$C | 45$^o$C | 50$^o$C | 55$^o$C | 60$^o$C |
| 1 | 0.00000 | -41.50 | -41.17 | -40.80 | -40.50 | -40.03 | -39.83 | -39.40 | -39.07 | -38.70 |
| 2 | 0.16947 | -39.60 | -39.37 | -39.03 | -38.73 | -38.47 | -38.23 | -38.07 | -37.73 | -37.40 |
| 3 | 0.31465 | -38.13 | -38.00 | -37.83 | -37.60 | -37.30 | -37.03 | -36.73 | -36.40 | -36.07 |
| 4 | 0.44042 | -36.90 | -36.70 | -36.53 | -36.27 | -36.00 | -35.73 | -35.50 | -35.03 | -34.73 |
| 5 | 0.55042 | -35.87 | -35.60 | -35.37 | -35.10 | -34.80 | -34.57 | -34.40 | -34.13 | -33.70 |
| 6 | 0.64744 | -34.73 | -34.57 | -34.33 | -34.13 | -33.87 | -33.60 | -33.23 | -33.03 | -32.70 |
| 7 | 0.73366 | -34.00 | -33.73 | -33.37 | -33.17 | -32.93 | -32.70 | -32.43 | -32.23 | -31.80 |
| 8 | 0.81078 | -33.10 | -32.83 | -32.63 | -32.37 | -32.17 | -31.93 | -31.60 | -31.20 | -30.70 |
| 9 | 0.88018 | -32.30 | -32.17 | -31.87 | -31.53 | -31.23 | -30.83 | -30.50 | -29.97 | -29.53 |
| 10 | 0.94295 | -31.70 | -31.37 | -31.00 | -30.63 | -30.17 | -29.80 | -29.40 | -29.10 | -28.80 |
| 11 | 1.00000 | -31.00 | -30.70 | -30.30 | -29.80 | -29.47 | -29.13 | -28.80 | -28.50 | -28.20 |

**Table.4:** Mole fraction of Acetic acid in Toluene + Acetic acid chemical mixture and Output power at various temperatures (from 20$^o$C to 60$^o$C) for the operating wavelength of the source 660nm and depth of immersion is 3cm.

| S. No. | Mole fraction of Acetic acid in mixture | Output Power (dBm) at various temperatures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20$^o$C | 25$^o$C | 30$^o$C | 35$^o$C | 40$^o$C | 45$^o$C | 50$^o$C | 55$^o$C | 60$^o$C |
| 1 | 0.00000 | -44.47 | -44.07 | -43.63 | -43.27 | -42.87 | -42.57 | -42.13 | -41.80 | -41.40 |
| 2 | 0.16947 | -42.27 | -42.03 | -41.67 | -41.43 | -40.97 | -40.63 | -40.37 | -40.10 | -39.70 |
| 3 | 0.31465 | -40.50 | -40.30 | -40.10 | -39.87 | -39.57 | -39.30 | -38.97 | -38.50 | -38.10 |
| 4 | 0.44042 | -39.13 | -38.87 | -38.67 | -38.30 | -37.93 | -37.63 | -37.33 | -37.07 | -36.70 |
| 5 | 0.55042 | -37.80 | -37.50 | -37.23 | -36.97 | -36.67 | -36.47 | -36.20 | -35.80 | -35.40 |
| 6 | 0.64744 | -36.60 | -36.40 | -36.13 | -35.80 | -35.50 | -35.30 | -34.90 | -34.67 | -34.17 |
| 7 | 0.73366 | -35.63 | -35.37 | -35.03 | -34.77 | -34.53 | -34.23 | -33.93 | -33.67 | -33.10 |



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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 0.81078 | -34.73 | -34.40 | -34.13 | -33.87 | -33.57 | -33.23 | -32.93 | -32.53 | -32.03 |
| 9 | 0.88018 | -33.77 | -33.47 | -33.17 | -32.73 | -32.37 | -31.87 | -31.53 | -31.20 | -30.83 |
| 10 | 0.94295 | -32.93 | -32.50 | -32.13 | -31.67 | -31.20 | -30.90 | -30.50 | -30.23 | -29.90 |
| 11 | 1.00000 | -32.13 | -31.70 | -31.23 | -30.80 | -30.50 | -30.17 | -29.80 | -29.53 | -29.30 |

## RESULTS AND DISCUSSION

The presence of mole fraction of Acetic acid in the mixture of Toluene + Acetic acid were calculated theoretically using the formula.

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

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

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

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

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

$\rho_1, \rho_2$: Densities of chemicals ($kg.m^{-3}$)

$V_1$, $V_2$: Volumes of chemicals (liters)

The dependence of refractive index on mole fraction of Acetic acid in Toluene + Acetic acid mixture was presented in the form of graphs [fig.-1]. The percentage of concentration of Acetic acid in Toluene + Acetic acid was obtained for each and every liquid mixture and was related to the variation in refractive index [fig.-2].

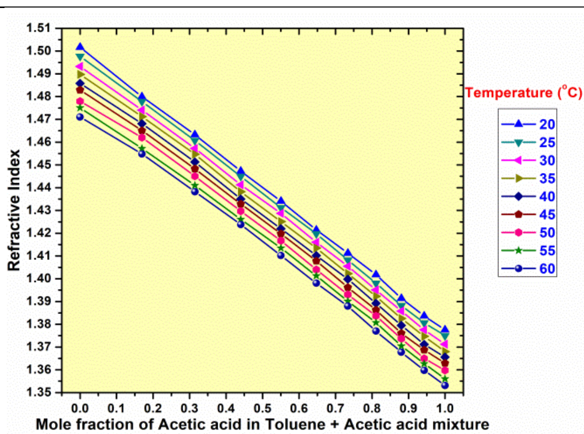


**Fig.1:** Relation between Mole fraction of Acetic acid in Toluene + Acetic acid mixture and Refractive index.

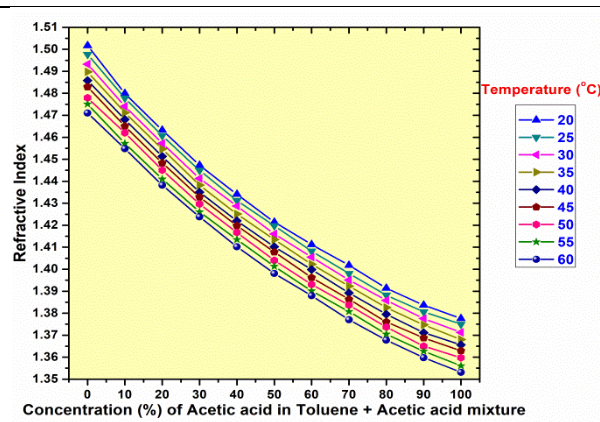


**Fig.2:** Relation between Concentration (%) of Acetic acid in Toluene + Acetic acid mixture and Refractive index.

It was observed that the refractive index of each mixture decrease with increase in the temperature from 20°C to 60°C and results are plotted in the graph [fig.-3]. The mutual dependence of mole fraction, refractive index and temperature were shown in a 3D graph for the simultaneous analysis [fig.-4].



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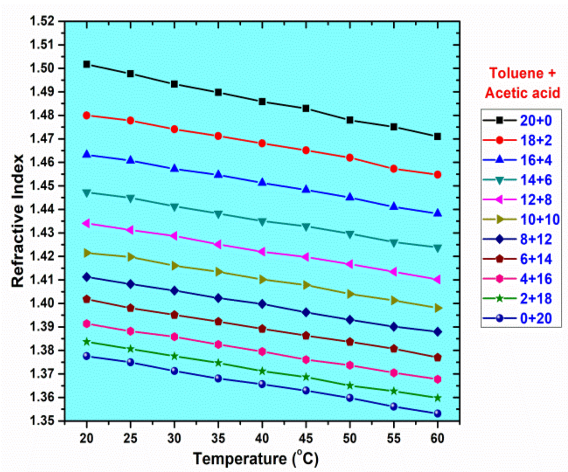


**Fig.3:** Relation between Temperature and Refractive index of Toluene + Acetic acid mixtures.

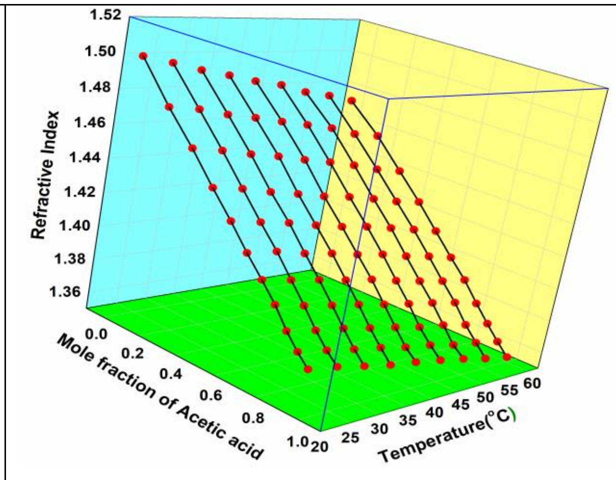


**Fig.4:** Relation between Mole fraction of Acetic acid in Toluene + Acetic acid mixture, Refractive index and Temperature.

The study of output power with mole fraction of Acetic acid in the mixture of Toluene and Acetic acid reveals that, as the mole fraction of Acetic acid increases in the mixture, the output power increase with a proportional value. This study was undertaken at the immersion depths of U-shaped glass rod into the mixture as 1cm, 2cm and 3cm as three cases and the results are shown graphically [fig.5-7].

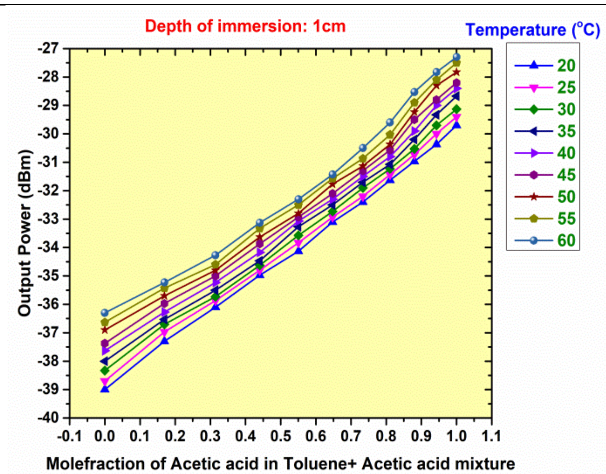


**Fig.5:** Relation between Mole fraction of Acetic acid in Toluene + Acetic acid mixture and Output power at depth of immersion is 1cm.

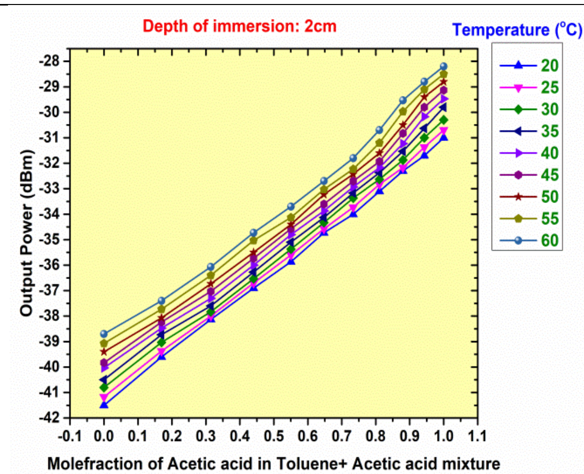


**Fig.6:** Relation between Mole fraction of Acetic acid in Toluene + Acetic acid mixture and Output power at depth of immersion is 2cm.



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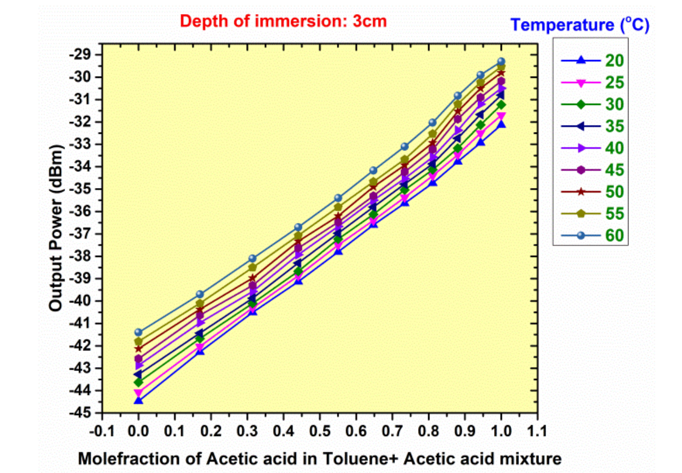


**Fig.7:** Relation between Mole fraction of Acetic acid in Toluene + Acetic acid mixture and Output power at depth of immersion is 3cm.

The temperature study of refractive index was carried out using a special temperature bath to rise the liquid temperatures from 20°C to 60°C and the output powers corresponding to each temperature of every mixture at different depths of immersions (1cm, 2cm & 3cm) was recorded and the behavior of output powers on temperature of each mixture was investigated and presented in graphs [fig.8-10].

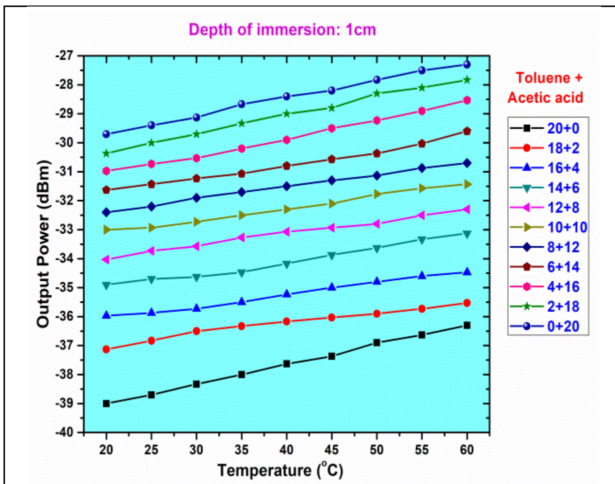


**Fig.8:** Relation between Temperature and Output power of Toluene + Acetic acid mixture at depth of immersion is 1cm

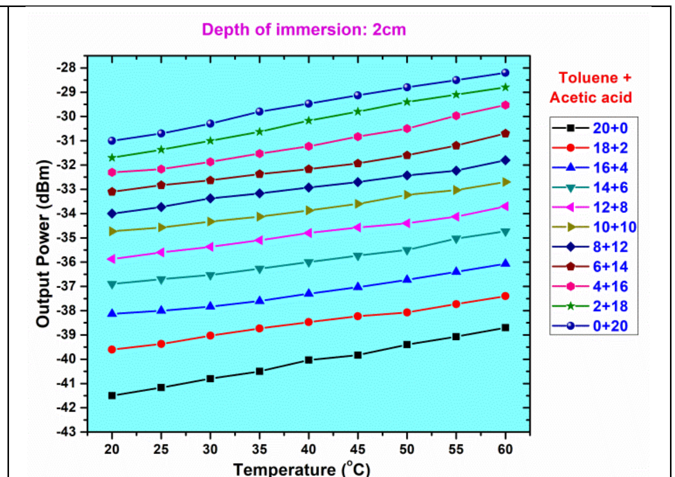


**Fig.9:** Relation between Temperature and Output power of Toluene + Acetic acid mixture at depth of immersion is 2cm



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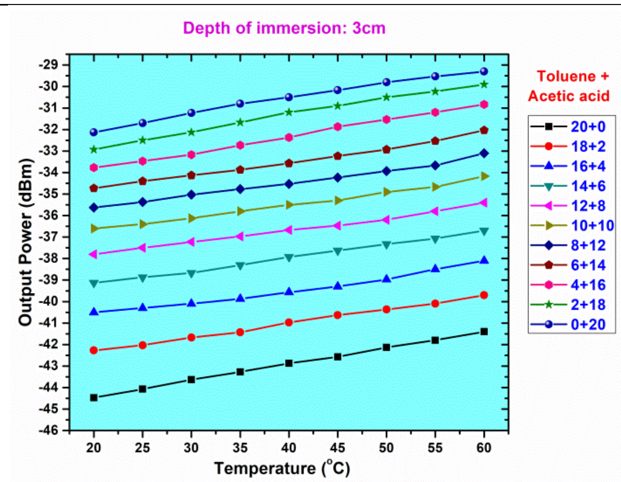


**Fig.10:** Relation between Temperature and Output power of Toluene + Acetic acid mixture at depth of immersion is 3cm

The relationships among the refractive index, temperature and output power were formulated and from the results 3D graphs were drawn at each depth of immersions [fig.11-13].

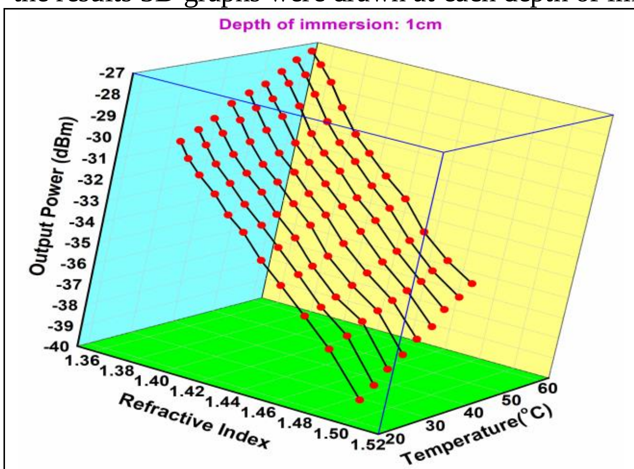


**Fig.11:** Relation between Refractive index, Output Power and Temperature of Toluene + Acetic acid at depth of immersion is 1cm

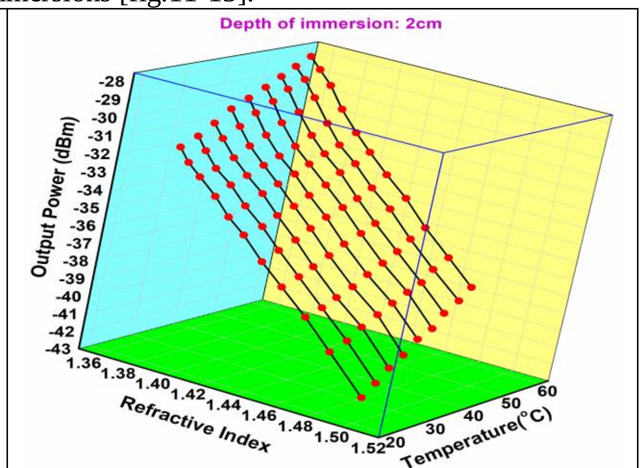


**Fig.12:** Relation between Refractive index, Output Power and Temperature of Toluene + Acetic acid at depth of immersion is 2cm



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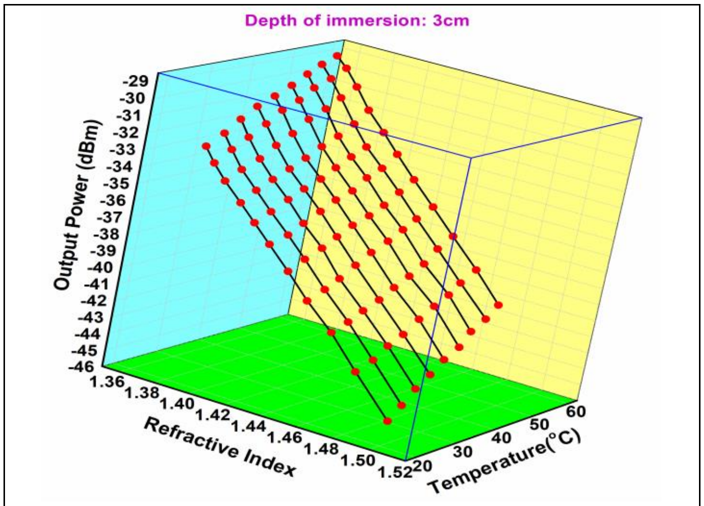


**Fig.13:** Relation between Refractive index, Output Power and Temperature of Toluene + Acetic acid at depth of immersion is 3cm

## CONCLUSION

The Sensor is designed with an idea of creating a clad removal portion as the sensing zone, at the middle of fiber length, which in turn can be made to interact with the measurand intended to be measured, thereby the light reaches the detector depends on the refractive index of liquids. The change in the refractive index with respect to temperature variation from 20$^{o}$C to 60$^{o}$C was investigated by recording the output power, as the output power varies in accordance with the refractive index of liquid mixtures at different temperatures and at the depths of immersions as 1cm, 2cm and 3cm. The mole fraction dependence of refractive index and output powers were also studied and results are presented in graphs. The mutual dependence of different sets of parameters mole fraction, temperature, refractive index and refractive index, temperature, output power for different depths of immersions were presented in 3D graphs.

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