Spectroscopic Signal Enabled Refractive Index Sensor Operating at the Temperature Range of 10ºC to 60ºC Using a Source of 660nm Wavelength

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Abstract

Determination of refractive index of liquids and solvents at various temperatures is of paramount importance in several chemical, pharmaceutical, bio-chemical, food processing, etc., industries. In the measurement of a parameter, the degree of accuracy plays a crucial role in deciding the application of the substance to a specific purpose. In the present paper a spectroscopic signal enabled refractive index sensor operating at the temperature range of 10ºC to 60ºC using a source of 660nm wavelength, which offers sensitivity of the order of fifth decimal place has been described. The present experimental setup consists of a borosilicate uniform U-shaped glass rod connected between a source of 660nm and a benchmark power detector. The working principle of the sensor involves the interaction between the evanescent wave of U-shaped glass rod and external medium consisting of mixture of Toluene and 1-Butanol at different temperatures ranging from 10ºC to 60ºC. The absorption of evanescent wave by the chemical solution used to attenuate and modulate the intensity of the light in the U-shaped glass of the fiber. The relationship between absorbing property of the external medium and the intensity of the light reaching the detector at various temperatures can provide the calibration of the sensor, which in turn used to measure the refractive index of liquids either dark or transparent in the temperature range of 10ºC to 60ºC.

Keywords: Evanescent wave, External medium, Intensity of the light, Refractive index sensor, Source of 660nm, Temperature range of 10ºC to 60ºC.

INTRODUCTION

The use of light for communication is the most primitive method and has been employed since beginning by the human beings. A dramatic change has been seen, using optical fibers for the communication purpose for the last forty years, replacing the existing copper communication system across the globe, offering tremendous advantages. Though optical fibers essentially used for communication purpose, they

are also used in sensing mechanism in measuring several environmental parameters for the last few decades. According to literature survey optical fibers can be employed for variety of detecting mechanisms to measure several environmental parameters like density, temperature, salinity, pressure, strain, concentration, displacement, speed, acceleration, chemical activity, etc. [1-4]. The significant characteristic advantage of fiber optic sensors makes them to be applied to measure a wide range of parameters and fields competing with their conventional electrical counter parts. The advantages of optical fiber sensors including cost effectiveness, ruggedness, being immune to RFI and EMI, light in weight, portability with miniaturized size, makes them to dominate over traditional sensors at various applications. Thus, these sensors can be used over a wide range of fields and industries such as science and technology, military, medicine, pharmaceutical, food processing security system, banking and also in civilian applications as reported in literature [5-16].

The sensing mechanism primarily consists of two components i.e. a measuring quantity and some measurand quantity. In the FOS mechanism, the light plays the role of measuring quantity, whose properties such as intensity, phase, frequency and wavelength are modulated in accordance with the variations in the measurand quantity. Based on the modulation of the light, the sensors can be classified broadly into two categories, 1.Extrinsic fiber optic sensors, 2.Intrinsic fiber optic sensors. In the intrinsic fiber optic sensors the light modulation takes place within the fiber, while in the extrinsic fiber optic sensors, the light modulation takes place outside of the fiber [17-21]. The FO sensors further can be classified based on the modulation of the parameter of the light, 1.Intensity modulated FO sensors, 2.Phase modulated FO sensors, 3.Frequency modulated FO sensors and 4.Wavelength modulated FO sensors. As light being a minute quantity, small change in the measurand parameter creates a large change in the light parameter. The definition for sensitivity is the change in the measurer quantity, corresponding to a change in the measurand quantity. Thus, the sensitivity of a sensor is

$$\text{Sensitivity } (\propto) = \frac{\text{Change in the magnitude of measuring parameter (light)}}{\text{Change in the magnitude of measurand parameter}}$$

Due to this character, the FO sensor offers higher sensitivities in comparison with conventional electrical sensors.

EXPERIMENTAL DETAILS

The various components used in the assembling of the experimental setup consists of a laser light source of 660nm wavelength, two multimode PCS fibers of same dimensions in which one is used as input fiber, the other is used as output fiber and a benchmark power meter compatible with the light coming from source. A glass rod bent in the form of "U" with specific dimensions is connected between input and

output fibers. Two additional setups (1.two burette system and 2.digital refractometer of modal number RX-7000i) are used to measure the volumes of liquid mixtures (Toluene+1-Butanol) and refractive indices of liquid mixtures. Liquid mixtures are prepared by taking Toluene and 1-Butanol in different proportions, making the total volume of each mixture is equal to 20ml. The mixtures are taken separately into a glass bottles and closed with air tight lids. Refractive indices values of each mixture was determined at different temperatures 10°C to 60°C, taking a fraction of liquid from each mixture and values are recorded.
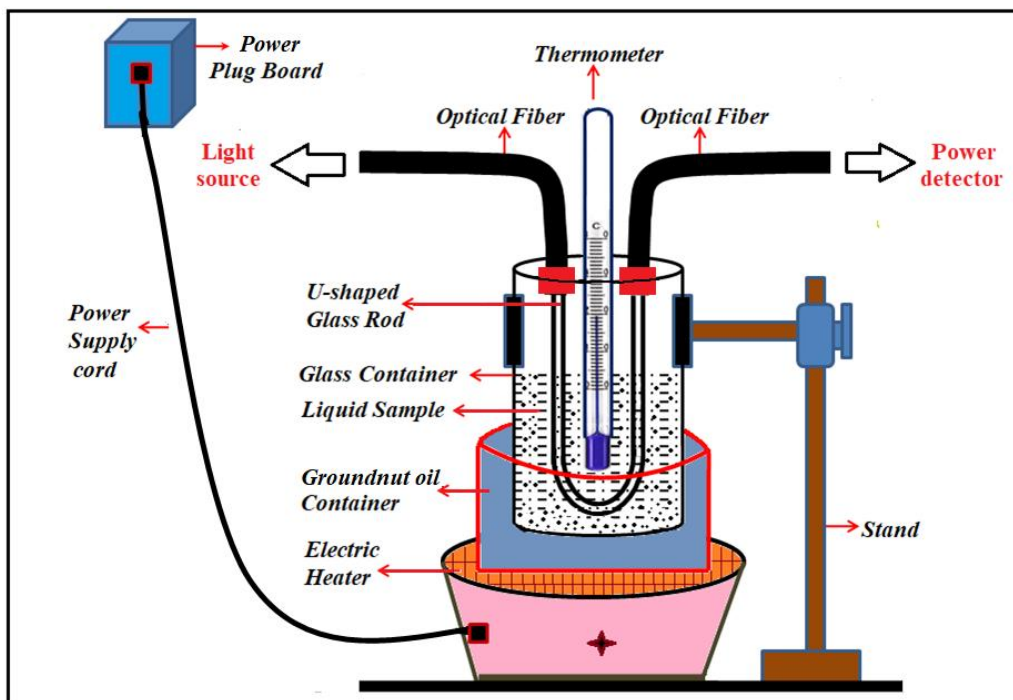
Fig.1: Experimental setup

1cm depth of immersion: In the first case of experiment, taking the first mixture with the combination of 20ml Toluene and 0ml of 1-Butanol, and immersion of the U-shaped glass rod into the liquid as 1cm, the power launched from the source was received at the detector. This procedure was repeated, maintaining the mixtures at different temperature using a temperature bath. As the mixtures are volatile in nature, the beaker containing the liquid mixture was heated indirectly using a temperature bath, consisting of a glass beaker in which the groundnut oil of required quantity was filled. Taking the other liquid mixtures, the method of measuring the output power was repeated at various temperatures, and values are recorded.

2cm depth of immersion: In the second part of the experimentation, the glass rod was immersed into the mixture to a depth of 2cm, thereby it is seen that, the light of interaction between the light in the glass rod which acts as core of the fiber and external medium (liquid mixture). The method of measurement of

output power was repeated with various mixtures surrounding the glass rod and rising the temperature of each mixture from 10ºC to 60ºC.

3cm depth of immersion: In the third case of experimentation, the depth of immersion of glass rod into the mixture was increased to 3cm, and data was collected by following the above mentioned method.

RESULTS AND DISCUSSION

Initially from the calculated values of mole fraction, concentration and experimentally obtained values of refractive index at different temperatures, the dependence of refractive index on mole fraction, refractive index on concentration of 1-Butanol in Toluene + 1-Butanol mixture and refractive index on temperature have been plotted in graphs [fig.2-4].
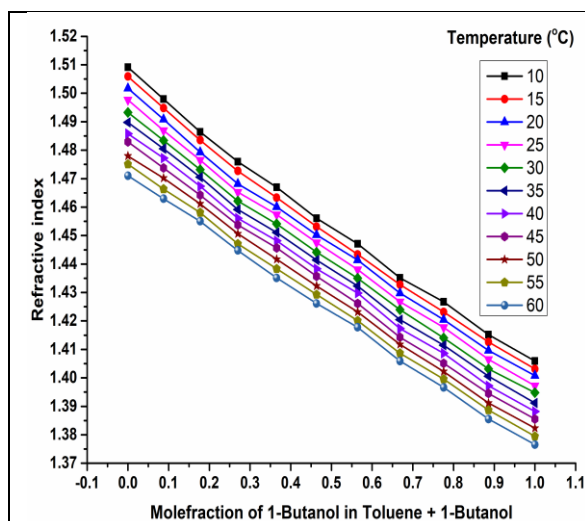
Fig.2: Relationship between Mole fraction of 1-Butanol and Refractive index.
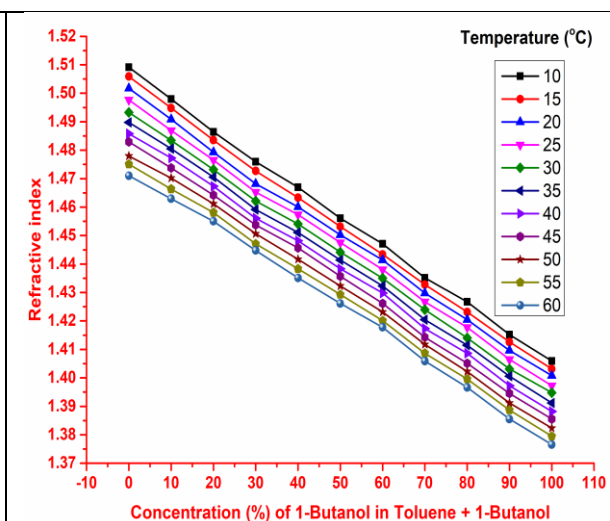
Fig.3: Relationship between Concentration (%) of 1-Butanol and Refractive index.
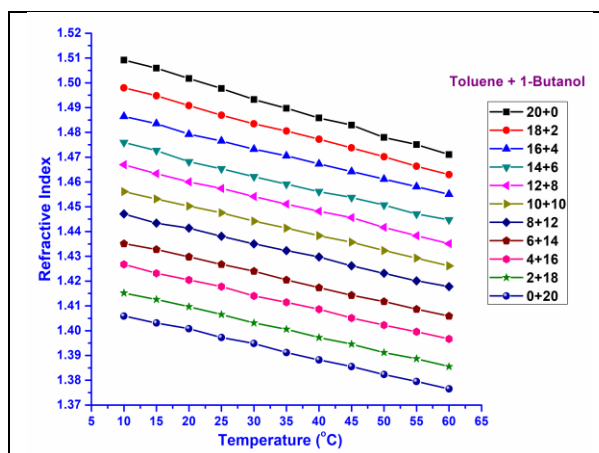

Fig.4: Relationship between Temperature and

> Refractive index of Toluene + 1-Butanol mixtures.

With a view to form the relationships among various parameters i.e. mole fraction, refractive index and temperature, and to represent the mutual dependence of various parameters on one another, a 3D graph is plotted [fig.5].

Fig.5: Relationship among Mole fraction of t-Butanol in Toluene + 1-Butanol mixture, Refractive index and Temperature.
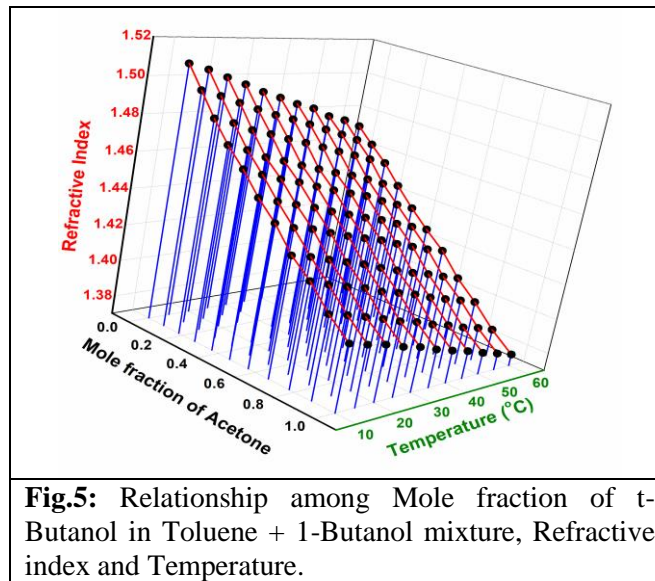
The study has been carried out using different depths of immersions (different interaction lengths between light in the U-shaped glass rod and external medium) taking 1cm, 2cm and 3cm. Fixing the depth of immersion of U-shaped glass rod into the mixture as 1cm, the corresponding output powers reaching the output detector at various temperatures were recorded and the dependence of output power on mole fraction of 1-Butanol in Toluene + 1-Butanol mixture plotted in graphs [fig.6].
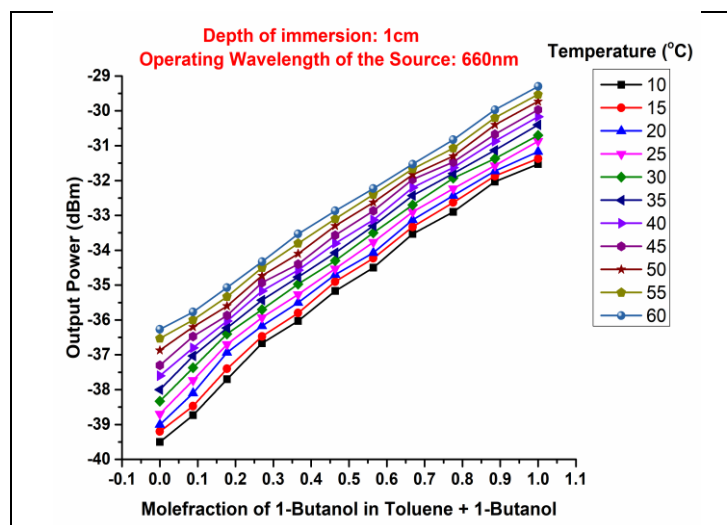
Fig.6: Relationship between Mole fraction of 1-Butanol and Output power at depth of immersion 1cm.

Similarly the variation of output powers were noted, when the U-shaped glass rod immersed in various mixtures and simultaneously rising the temperature corresponding to 2cm depth of immersions and results are presented in graph [fig.7].

Fig.7: Relationship between Mole fraction of 1-Butanol and Output power at depth of immersion 2cm.
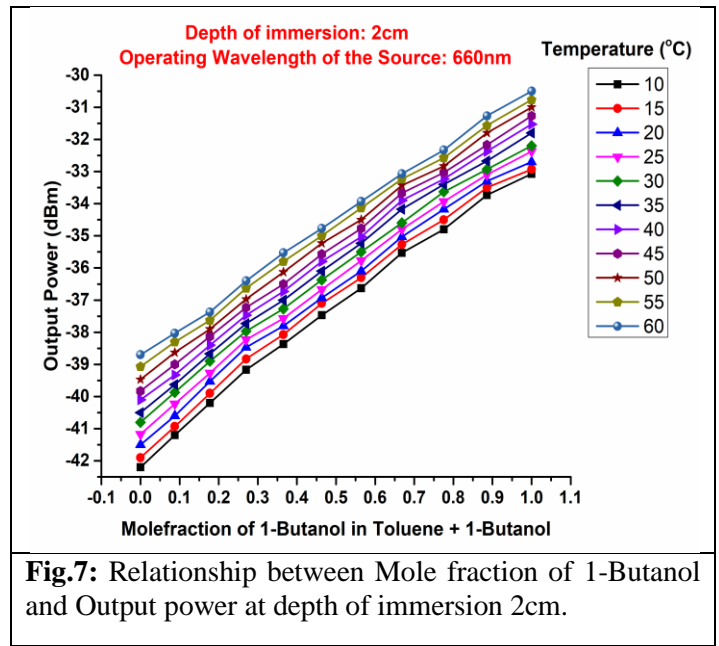
The same procedure repeated by selecting the depth of immersion equal to 3cm and results are plotted in graph [fig.8].

Fig.8: Relationship between Mole fraction of 1-Butanol and Output power at depth of immersion 3cm.
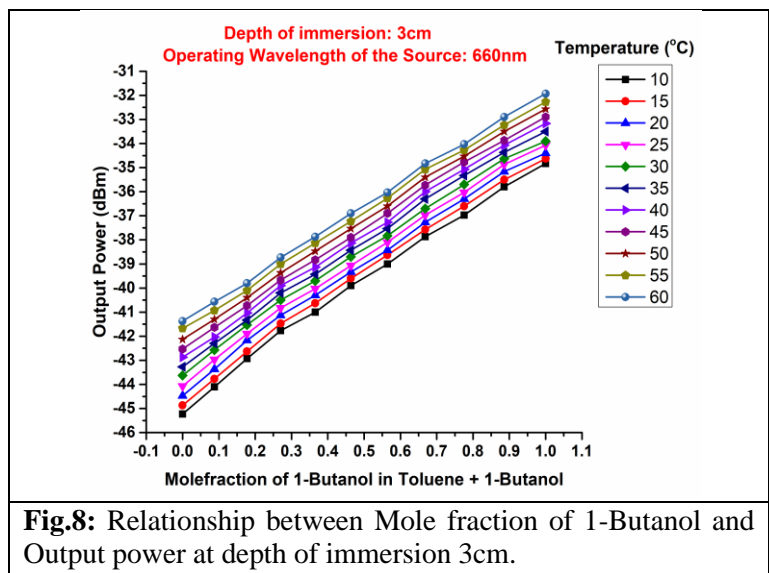
The sensitivity in the case of 1cm, 2cm and 3cm depths of immersions are measured and compared to decide the highest sensitive depth of immersion of glass rod into the liquid mixture. It is concluded that the U-shaped glass with highest depth of immersion i.e. 3cm, thereby the length of interaction becomes more offers highest sensitivity in comparison with other two.

The spectroscopic variation of the output signal due to interaction of light in the glass rod with the external cladding (liquid mixture) at various temperatures, corresponding to 1cm, 2cm and 3cm depths of immersions are presented in graphical form [fig.9-11].
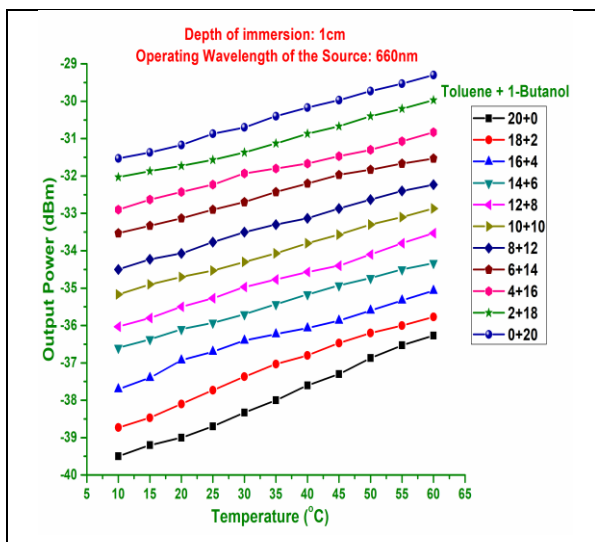

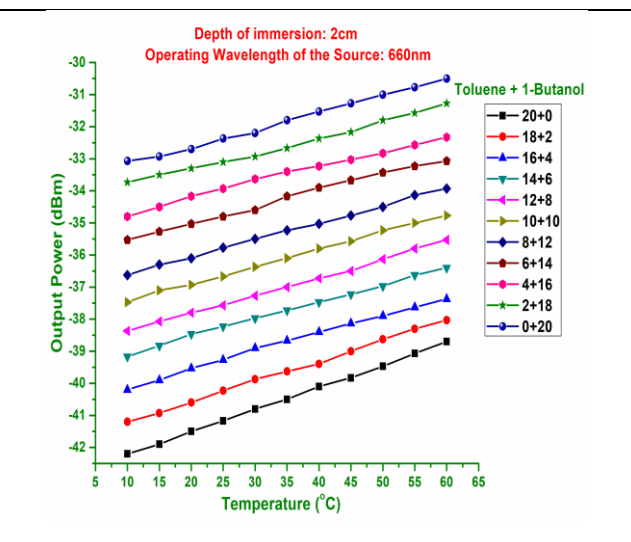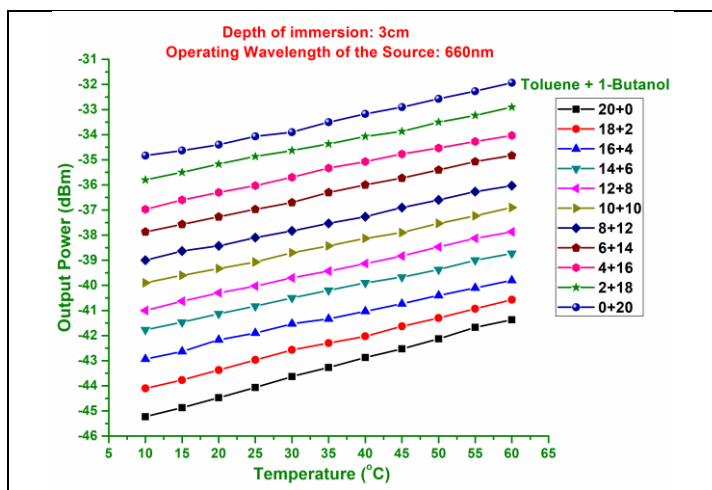|	
Fig.9: Relationship between Temperature and Output power of Toluene + 1-Butanol mixture at depth of immersion 1cm.	**Fig.10:** Relationship between Temperature and Output power of Toluene + 1-Butanol mixture at depth of immersion 2cm.

Fig.11: Relationship between Temperature and Output power of Toluene + 1-Butanol mixture at depth of immersion 3cm.

A strong relationship among output power, refractive index and temperature was observed in the above graphs. The mutual relationships among them are appears to be interesting and hence their graphical relationships are presented in 3D graphs [fig.12-14].
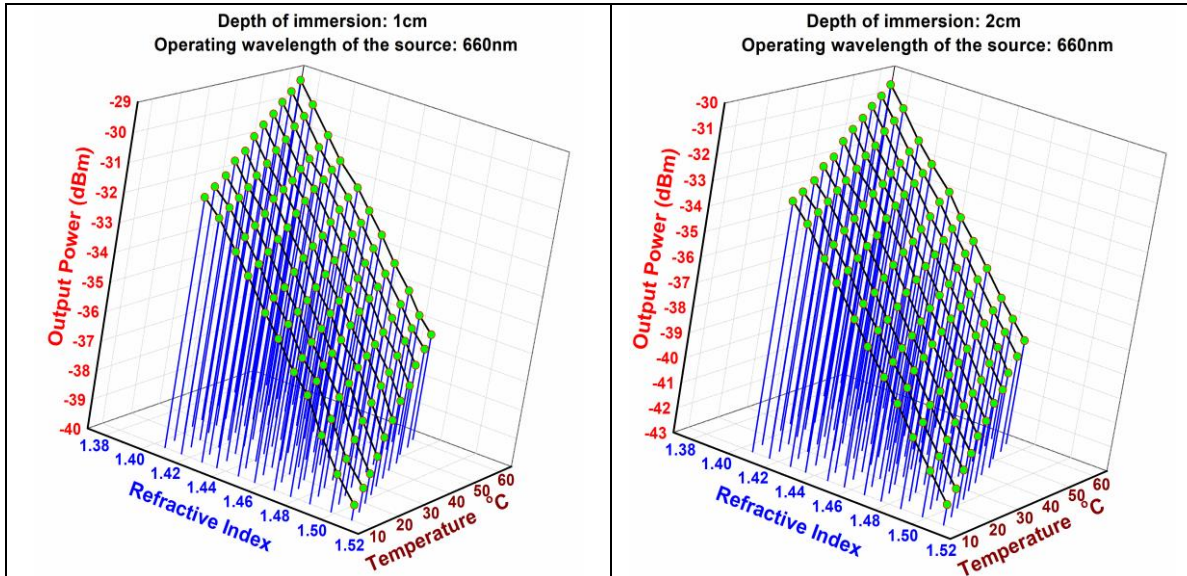

Fig.12: Relationship among Refractive index, Output Power and Temperature of Toluene + 1-Butanol at depth of immersion 1cm.

Fig.13: Relationship among Refractive index, Output Power and Temperature of Toluene + 1-Butanol at depth of immersion 2cm.
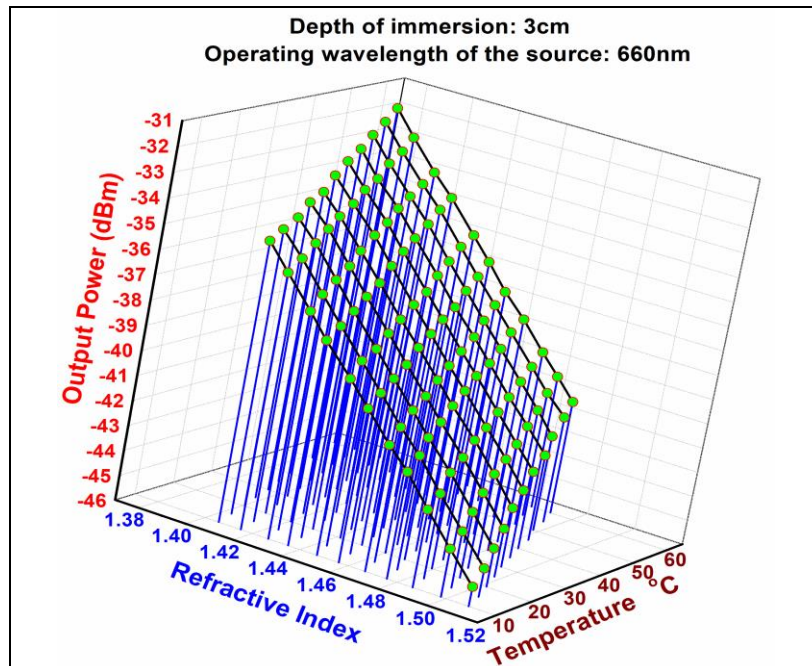

Fig.14: Relationship among Refractive index, Output Power and Temperature of Toluene + 1-Butanol at depth of immersion 3cm.

CONCLUSION

In the present paper it is proposed to study the design and characterization aspects of U-shaped glass based fiber optic sensor, intended to measure the refractive index. The experimental setup was assembled by connecting a U-shaped glass rod in between two PCS fibers and by connecting the other ends of the fibers, one to the source and other to the detector. The sensitivity of the sensor was enhanced by increasing the length of interaction of light in the core with external liquid cladding in terms of increased depth of immersion and the study was carried out at different temperatures the range between 10ºC to 60ºC.

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