International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 09 , September 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

U – Shaped glass rod based Optical Fiber Sensor – distribution of power between evanescent waves and meridional waves during transmission of light

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ABSTRACT

Various kinds of conventional sensors like electrical, mechanical and electronic and magnetic etc. are being used to measure several environmental parameters since long. Optical fibers apart from being used for telecommunication purposes, of the late they are also used as sensing devices for various medical, domestic, military, industrial, scientific, engineering and consumer applications. When a U – Shaped glass rod connected between the input fiber arm which in turn connected to a light source and the output fiber arm which in turn connected to a power meter used as an extrinsic sensing element to sense transparent liquids whose refractive index values lie between 1.3n_D and 1.5$n_{D,}$ power redistribution takes place between the meridional rays travelling through the glass rod and evanescent rays that travel out of the glass rod into the parameter acting as a cladding that surrounds the rod. The present paper reports the distribution of power between the meridional rays and the evanescent rays, when in the fiber optic sensing system a U – shaped solid glass rod is used as sensing element.

Keywords: Evanescent waves, Input fiber arm, Meridional waves, Mole fraction, U – Shaped solid glass rod

I. INTRODUCTION

When the science of optical fibers for communication was evolving around early seventies, it was observed that the transmission characteristics of optical fibers are highly sensitive to certain external perturbations like macro-bends, micro-bends, joints, temperature, pressure, strain, etc. and certain internal perturbations like refractive index, density inhomogeneity, dopants, Hydroxyl ions etc. At the same time on the observation of optical fiber sensitivity to these perturbations, an alternative thought began in the scientific world to design a large number of fiber optic sensors [1]. Compared to conventional sensors the fiber optic sensors offer substantial benefits such as safe in explosive environment, immune to EMI, highly reliable, high voltage insulation, low volume and weight, resistant to nuclear and ionizing radiations, chemically inert, large bandwidth etc. [2-5]. These advantages help measuring various kinds of parameters like strain, vibration, radiation, liquid level, temperature,

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

pressure, liquid refractive index, electric current, rotation, displacement, acceleration, acoustic, electric and magnetic fields and so on. The design, the working principle, the mechanism and the sensitivity criteria of a particular sensor depends mainly on the parameter that is to be sensed. The evanescent wave absorption mechanism based sensors have become more popular as their application in chemical analysis is much pronounced for the past few decades [6-8]. In the present work by using a U – shaped solid glass rod as sensing probe between the two fiber arms the fiber optic sensor is constructed and distribution of power between the glass rod and the surrounding liquid is studied and the results are presented.

II. MATERIALS AND METHODS

Two plastic fibers of 200 / 230µm were used in the constitution of the sensing system. The glass rod of 1.0mm in diameter was bent into the form of a U – shape having 5cm length to a bend radius of 0.5cm to enhance the sensitivity as the decrease in bend radius increase the sensitivity for which the borosilicate glass was selected. The U – shaped glass rod connected to the two fiber arms was exposed to an absorbing liquid. The light is launched at one end collected at the other end where the glass rod acts as core of the fiber and the surrounding liquid act as a cladding of the fiber. The power reaching the receiver depends on the absorption of the evanescent field in the liquid surrounding the glass rod. The concentration of the liquid or density and hence the refractive index of the liquid determines the power transmitted through the fiber. Again the absorption of evanescent field will be decided by two parameters, the length of the glass rod and the penetration depth of the evanescent field into the liquid. More is the length of the glass rod, more is the number of reflections of the meridional rays and hence more light will escape in the form of evanescent wave into the liquid suffering heavy loss to the transmitted power. Thus the power reaching the detector is the measure of amount of power exchanged from glass core into the cladding i.e. the liquid which is surrounding the U-shaped glass rod in this case.

Power exchange: The propagation of electromagnetic field within a guiding structure is in the form of a set of discrete pattern of the field named natural modes. The condition for the light guiding through the fiber is that the diameter of the core must be more than the wavelength of the light radiation. Thus the necessity arises to define the cutoff condition for an optical fiber in terms of wavelength (frequency) that a fiber can support. The distribution of the modes can be described by cutoff condition as the solution for the eigenvalue equations. The cutoff condition can be expressed in its typical form as

$$V = \beta a$$

Where,

V is the normalized cutoff frequency or V number

'a' is the radius of the core of the fiber and

β, is the wave propagation constant

The total number of modes that the multimode fiber transmits is denoted by N. The number of modes N, in terms of normalized frequency V is given by

$$N = \frac{V^2}{2} \text{ , for step index fibers}$$

Where V is the normalized frequency, given by

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ISSN (O) 2319 - 8354
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$$V = \frac{2\pi a}{\lambda}(n_1^2 - n_2^2)^{1/2}$$

Where,

n_1, is the refractive index of the core

n_2, is the refractive index of the cladding

'a' is the radius of the core

λ , is the source wavelength

By adjusting the parameters 'a', λ, n_1, n_2 the V number has to be reduced to restrict the number of modes supported by the optical fiber.

Bending the solid glass rod diminishes the higher order modes that propagate through the fiber. This change affects the dispersion and distribution optical power between meridional rays and evanescent rays. Most of the light will be converted into evanescent wave in this case.

A further mechanism of power distribution arises when the refractive index of the cladding or the liquid surrounding the U-shaped glass rod is increased. The reverse is true when the concentration of the liquid is decreased, and most of the light radiation remains in the fiber core as meridional wave.

III. EXPERIMENTAL ARRANGEMENT

A solid glass rod bent in the form of U-shape with certain specific physical parameters is used in the experiment [Fig.1] to form a sensing zone to study the power distribution.

Geometrical parameters of sensing system:

Thickness the glass rod: 1mm

Height of the glass rod: 5cm

Width between the two prongs: 1cm

Depth of the curvature = 1cm,

Radius of the curvature: 0.5cm

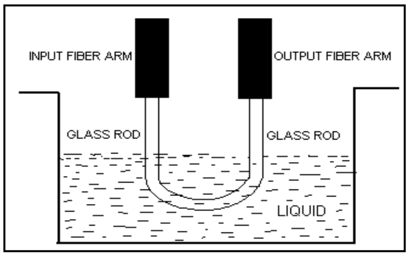

Fig. 1: Schematic of the sensor

IV. POWER DISTRIBUTION

The mixtures of two chemicals Methanol and Benzene were selected to calibrate the sensor. The chemical mixtures were taken in different proportions each time making the total volume of the mixture equal to 10ml by using a burette system. The refractive index of Methanol (CH_3OH) is $n_D^{30} = 1.3314$ and the r. i. of Benzene is

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ISSN (O) 2319 - 8354
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$n_D^{30} = 1.5$ and when the mixtures of these two chemicals taken in different proportions making the total volume always equal to 10ml then the dynamic range of the mixtures run from 1.3314n_D^{30} when the benzene taken was zero and the methanol taken was 10ml to 1.5n_D^{30} when the mixture taken to be methanol taken was zero and benzene taken to 10ml. Thus the operation range of the sensor is from 1.3314n_D^{30} to 1.5n_D^{30}.

The experimental arrangement consists of light source of 6330Aº to launch the light into the sensor system and a bench mark light detector both connected to the U-shaped glass rod [Fig.:2].

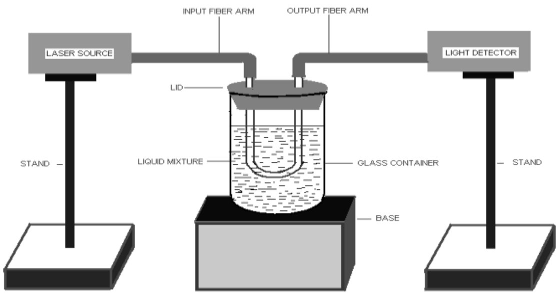

Fig. 2: Experimental arrangement of sensor

Each time when the chemical mixture with different proportions exposed to the sensor which acts as a cladding to the U-shaped glass rod, the output power was noted and tabulated and at the same time the refractive index of each mixture was noted by using Abbe's refractometer and both were tabulated. Graph is drawn by taking refractive index and output power [Fig.: 3].

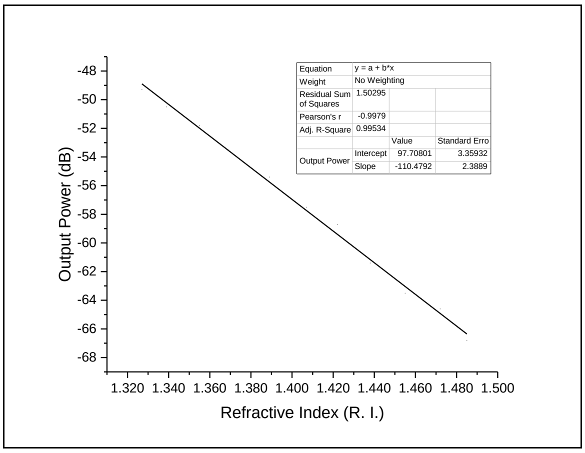

Fig.3: Methanol mixed in Benzene

From the graph [Fig.3] it can be noticed that guided power (meridional waves) decreases with the concentration (refractive index) of the mixture surrounding the sensing probe. Thus in this case it can be argued that a fraction of meridional waves that confine within the core of the fiber are converted into the evanescent waves that confine in the cladding. Thus the power is redistributed between meridional waves and evanescent waves in the guiding medium during the course of transmission of light radiation through the fiber.

This was tried out with other liquid mixture such as cyclohexane mixed in benzene. Similar results are obtained in this case also and the same was represented in graphical form [Fig.4].

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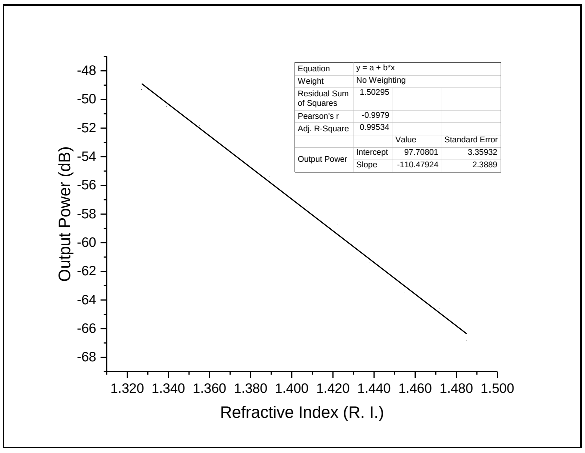

Fig.4: Cyclohexane mixed in Benzene

Mole fraction: The study of power distribution gives much clarity and when it is analyzed by using the concept of mole fraction of the liquids used in the work. Binary mixtures of Methanol and Benzene were prepared by mixing 'x' cc of Methanol (or Cyclohexane) in 'y' cc of Benzene. The composition of the binary mixture is varied by varying x and y in known steps keeping the sum '(x + y)', a constant. The concentration of Methanol in the binary mixture is expressed in mole fraction as:

Mole fraction of Methanol,

$$M_f = [x (M_1/d_1) / [(x (M_1/d_1) + y (M_2/d_2)]$$

M_1 = Molecular weight of Methanol

M_2 = Molecular weight of Benzene,

d_1 = Density of methanol and

d_2 = Density of Benzene.

The results of the variation of output power with the change in the mole fraction of methanol mixed in Benzene were plotted graphically [Fig. 5]. From the figure, the variation of output power increase with increasing the mole fraction of the methanol in the fixed 10ml concentration of benzene. With the refractive index of benzene (R. I. =1.5) is more than the refractive index of benzene (R. I. =1.3314), the concentration of the benzene is more than the concentration of methanol when the volumes of the both the liquids are the same (10ml in this case). The original concentration of benzene goes on decreasing if the methanol added by mixing 1ml, 2ml, 3ml, 4ml, etc. into benzene (10ml). Hence, the depth of the absorption of meridional wave into the liquid surrounding the medium decreases with addition of methanol into benzene, less amount of light escapes into the liquid cladding as evanescent wave and at the same time more light can be observed at the output. Thus, the increase in mole fraction of methanol in benzene, increase the output power of the detector at the receiver end.

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ISSN (O) 2319 - 8354
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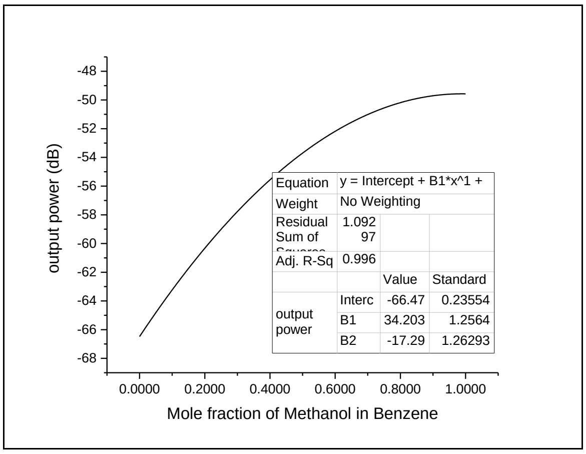

Fig. 5: Mole Fraction of CH_3OH in C_6H_6

This procedure was repeated for Cyclohexane mixed in Benzene. The results of variation of output power with change in the mole fraction of the cyclohexane in benzene was plotted graphical in the Fig. 6

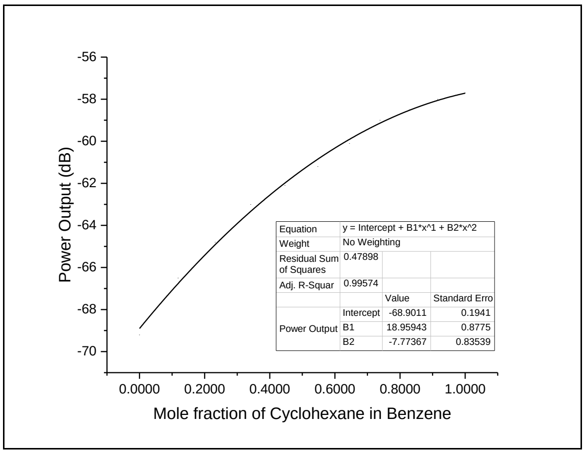

Fig. 6: Mole fraction of C_6H_{12} in C_6H_6

V. CONCLUSION

From the studies with chemical mixtures such as methanol mixed in benzene (C_6H_6) and cyclohexane (C_6H_{12}) mixed in benzene, it is concluded that the guided power in the medium will be distributed if the cladding refractive index changed at any portion of the optical fiber maintaining still the condition for total internal reflection, that $n_1$of the core is greater than the cladding n_2 i. e. $n_1 > n_2$. The distribution of power into the cladding although unnecessary when the fiber optic system is used for telecommunication purposes, its use and advantages in the case when the fiber optic system is used as measuring (sensor) system to measure any environmental parameter finds in innumerable number of application covering almost all walks of human life.

VI. ACKNOWLEDGEMENT

The author is grateful to his children Ms. Haindavi Shivani and Mr. Sai Jaihind for sacrificing their precious time missing me and keeping away themselves from spending most of the time with me during writing the paper and for their help in preparing the electronic form of the manuscript prepared by me. And the help rendered in plotting the electronic form of graphs assisting in the process of submitting the paper to the conference.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

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