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Estimation of the Content of Iodine in the Iodized Salt Solution using a Fiber Optic U- Shaped Sensing Element

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ABSTRACT: *The content of Iodine in the salt used for domestic purpose especially as culinary ingredient plays a crucial role in the food processing industry. In order to estimate the content of Iodine in the Iodized salt solution, an optical fiber operating at 630nm is used in the present work. The design of the fiber optic probe basically involves a U- shaped borosilicate solid glass rod which is well calibrated having the dynamic range from $1.3n_D$ to $1.5n_D$ exposed to the common salt solution and to the solution of Iodized salt. The light source is connected to the input multimode fiber (200/230 µm) arm by using a suitable SMA connector. The other end of the input fiber arm is connected to the one of the ends of the U- shaped glass rod by using glue, which is used to join the glasses. The other end of the glass rod is connected to the one of the ends of the output multimode fiber (200/230 µm) arm so that light emerging from the glass rod will enter into the output fiber arm. The second end of the fiber arm is in turn connected to optical power meter using another suitable SMA connector. The sensor so designed is initially immersed in a beaker containing common salt solution and the output power is noted for several concentrations. The method was repeated for various concentrations of Iodized salt solution. As the concentration of the Iodine in the Iodized salt increases, it is observed that the output power also increases. Similar results were observed even with common salt solution. Thus the presence of the content of Iodine in the Iodized salt solution studied by measuring the influence of it on the light reaching output end and thereby an estimation is made in the present work. The results obtained are in good argument with the other existing conventional methods reported in the literature.*

KEYWORDS: ***Content of Iodine, common salt, U-shaped glass rod, Dynamic range, culinary ingredient***

1. INTRODUCTION

For the last few decades there is a growing implementation of optical fibers in sensing applications for measurement of various physical and chemical parameters, including pH, chemical concentration, displacement, acceleration, rotation, current, magnetic field, temperature, refractive index and pressure and so forth., although the major application of optical fibers has been in telecommunication. As the measurement of such parameters arises in the electrical power industry, automobiles, industrial process control and the defense sector, as the fiber optic sensors are widely used and hence find applications in those areas.

The optical fiber sensor basically may be defined as a device in which an optical signal is changed by an external stimulus, such as temperature, refractive index, strain, electric field, magnetic field, liquid level, chemical activity etc., in some reproducible manner. A wide range of optical fiber sensing devices can be constructed based on the change in the characters of optical beam such as intensity, wavelength spectrum, state of polarization and phase. In optical fiber sensors any one of these characters or a combination of these may be modulated by the parameter to be measured.

In a typical optical fiber sensor, light from a source such as an LED or a laser diode is guided by an optical fiber to the sensing zone created in the sensing system. At the region of sensing the light will be made to interact with the external parameter to be sensed. Due to the interaction of light with the parameter, one of the four characters of the light gets modulated. The modulated light beam sent via another optical fiber having the same characters as that used as the input fiber, for detection and for processing. Optical fiber sensors offer

significant potential advantages in applications, where high levels of electromagnetic interference, cheap in cost, construction simplicity, intrinsic safety or high sensitivity is of paramount importance [1- 7]. The constitution of a sensor system, the mechanism of sensing and the theoretical concepts behind have been reported in the literature [8 – 12]. In the present work, an attempt is made to design a novel U-shaped glass rod based optical fiber sensor operated at a wavelength of 630 nm for the estimation of potassium iodide in the common salt solution. The method developed is very simple, and the weight of the entire sensor system is almost negligible, and the overall system is portable and serves as a versatile nature in measuring the various environmental parameters around.

2. EXPERIMENTAL METHOD

In the experimental arrangement, two short length plastic optical fibers (PCS) of 200/230 µm diameter are used, one as input fiber arm and the other as output fiber arm in between which a glass rod bent in the shape of U is used as a novel sensing probe which in turn form a sensing zone of the sensor. The end of the input fiber arm is connected to a semiconductor laser source operating at the wavelength of 630 nm by using a SMA connector. The end of output fiber is connected to a bench mark made power meter by using another SMA connector. The sensor of such arrangement is called an extrinsic optical fiber sensor as the light modulation takes place outside of both the fibers used. The fibers in this case merely act as conduits just to take the light to and from the sensor head, the U-shaped glass rod. The U- shaped solid glass rod so connected simply acts as core in the sensing region and any liquid that is maintained surrounding glass rod whose refractive index is less than the core refractive index, acts as a cladding in the sensing region. Then the absorption of light takes place according to the absorptive property (absorption coefficient) of the liquid used as a cladding. The depth of absorption also depends on the concentration of the liquid, as concentration increases, the loss of light reaching the detector increases. The loss of light also varies due to two physical parameters of the –shaped glass sensing probe, the bend radius of the U-shaped glass rod, and the diameter of the solid glass rod. The loss of light increases, if the bend radius decreases of the sensing probe, and also increases with decrease in the diameter of the glass rod. If P_0 represents the total power injected into the guided modes of fiber 1, then the power in the guided modes of fiber 2 is given by,

$$P_b = P_0 \frac{n_1^2 - n_l^2}{(n_1^2 - n_{cl}^2)} \tag{1}$$

It is evident from this equation that power coupled to fiber 2 through the U-shaped probe increases linearly with proportional decrease in n_l^2.

Consider a multimode step index optical fiber in which the cladding has been replaced locally by the absorbing fluid. When P is the transmitted power by the fiber in the absence of the absorbing fluid, then in the presence of the fluid the power transmitted by the fiber is given by:

$$P = P_0 \exp(-¥L) \tag{2}$$

Where, ¥ is evanescent coefficient of absorption of the fluid and L is the length of the uncladded portion of the fiber. At the sensing region ¥, in the case a ray making an angle, ¯, with normal to the cladding interface is given by:

$$¥(¯) = \frac{\sim^{a} n_2 \cos^{¯} \cot^{¯}}{2®° n_1^2 \cos^{2¯}{}_c (\cos^{2¯}{}_c - \cos^{2¯} \sin^{2¯}{}_¤)^{1/2}} \tag{3}$$

Where, $¯_¤$ is the angle of skewness, ~ is the fluid bulk absorption coefficient and ° is radius of the core of the fiber. It may be noted for a fixed value of ¯, from equation (3), when the ray is meridional (i.e. $¯_¤ = ®/2$)

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the evanescent coefficient of absorption is maximum. With the increase in skewness, it decreases. It can be shown that the sensitivity $[-1/\mathrm{P}(d\mathrm{P}/dc]$ of the sensor is proportional to $L¥/\sim$, when the index of refraction of the absorbing fluid does not vary with c, the concentration of the fluid within the range of desired concentration. Thus, $¥/\sim$ for a given L, directly defines the sensitivity. It means, when the meridional rays are launched in the fiber, the sensitivity will be maximum. For the propagation of meridional rays in the optical fiber, using a microscope objective, the light is launched into the optical fiber from a laser which is a collimated source. The power, $d\mathrm{P}$, for such an illumination, arriving at the axial point of the fiber end face between the angles, $\bar{}_0$ *and* $\bar{}_0 + d\bar{}_0$ is proportional to $(\tan\bar{}_0 / \cos^2\bar{}_0)d\bar{}_0$, where $\bar{}_0$ is the angle of the ray with the axis outside the fiber. Using Snell's law and $\bar{} = 90^\circ - \bar{}_1$, where $\bar{}_1$ is the angle of the same ray with the axis of the fiber inside the core, we can write:

$$d\mathrm{P} \propto \frac{n_1^2 \sin\bar{}\cos\bar{}}{(1-n_1^2\cos^2\bar{})^2} d\bar{}$$

Hence, for the launched meridional rays into the sensing region, the effective evanescent absorption coefficient for the angles in the range $(\bar{}_1, \bar{}_2)$ with respect to the normal to the core cladding interface is given by:

$$¥_{eff}(\bar{}_1, \bar{}_2) = \left[\int_{\bar{}_1}^{\bar{}_2} \frac{\sin\bar{}\cos\bar{}}{(1-n_1^2\cos^2\bar{})} ¥(\bar{}) d\bar{} \Big/ \int_{\bar{}_1}^{\bar{}_2} \frac{\sin\bar{}\cos\bar{}}{(1-n_1^2\cos^2\bar{})^2} d\bar{}\right] \quad (4)$$

For the propagation of all bound rays in the sensing region, $\bar{}_1 = \sin^{-1}(n_{cl}/n_1)$ *and* $\bar{} = 90^\circ$. As shown in figure 1, let us consider a U – shaped sensing region. We consider a two dimensional approach to simplify the theoretical treatment of the probe. The rays in the region of sensing will be mainly meridional under this approach and will confine in the plane of bending.

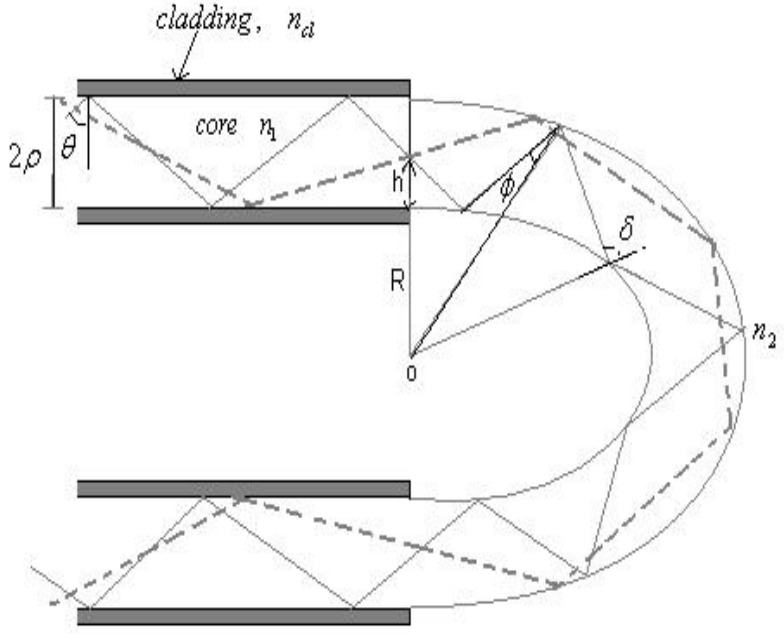

Fig. 1: Geometry of the U-shaped sensing region and the representation of a meridional ray travel in it.

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In the case of a two dimensional approach as mentioned above, the sensitivity calculated will be more than with the actual case, with decreasing skewness the sensitivity increases. The ray angle with the normal to the cladding core interface within the sensing region should be greater than the sensing region critical angle for the transmission through the sensing region. The ray can undergoes TIR at the outer surface and will not reach the inner surface at all (dotted ray) or a ray can undergo the total internal reflection (TIR) both at the inner and at the outer surfaces (continuous ray), which are the two possibilities in a U – shaped optical fiber. When ¯ defines in the straight fiber, the angle which a guided ray makes with the normal to the cladding core interface, then the corresponding angle ¤ at the bent core outer surface is given by the equation:

$$\sin ¤ = \left[\frac{R+h}{R+2°}\right]\sin ¯ \tag{5}$$

Where R is the bending radius, h, is from the cladding and core boundary, is the distance at which the ray is incident on the entrance of the sensor. Similarly, the angle ¢ of the ray of the bent core at the inner surface and is given by:

$$\sin ¢ = \left(\frac{R+h}{R}\right)\sin ¯ \tag{6}$$

Hence the angle ¯ is transformed to angles ¤ *and* ¢ from equations 5 and 6 respectively. Hence, for the sensing region outer surface, the effective evanescent coefficient of absorption will be given by:

$$\left[¥_{eff}(¯_1, ¯_2)\right]_{outer} = \frac{\sim ª n_1}{2[2®°(n_1^2 - n_1^2)]} \times \left[\begin{array}{l} \int_0^{2°}\int_{¤_1}^{¤_2} \frac{\cos^3 ¯\, d¯\, dh}{(1-n_1^2\cos^2 ¯)^2 (n_{12}^2 \sin^2 ¯ - 1)^{1/2}} \\ \div \int_0^{2°}\int_{¤_1}^{¤_2} \frac{\sin ¯ \cos ¯\, d¯\, dh}{(1-n_1^2\cos^2 ¯)^2} \end{array}\right] \tag{7}$$

$$¤_1 = \sin^{-1}\left[\frac{(R+h)n_{cl}}{(R+2°)n_1}\right], \text{ And}$$

$$¤_2 = \sin^{-1}\left(\frac{R+h}{R+2°}\right)$$

Similarly, for the inner surface of the sensing region, the effective evanescent coefficient of absorption can be written as:

$$[¥_{eff}(¢_1, ¢_2)]_{inner} = \frac{\sim ª n_1}{2[2®°(n_1^2 - n_2^2)]} \times \left[\begin{array}{l} \int_0^{2°}\int_{¢_1}^{¢_2} \frac{\cos^3 ¯\, d¯\, dh}{(1-n_1^2\cos^2 ¯)(n_{12}^2 \sin^2 ¯ - 1)^{1/2}} \\ \div \int_0^{2°}\int_{¢_1}^{¢_2} \frac{\sin ¯ \cos ¯\, d¯\, dh}{(1-n_1^2\cos^2 ¯)^2} \end{array}\right] \tag{8}$$

Where,

$$¢_1 = \sin^{-1}\left[\frac{(R+h)n_{cl}}{Rn_1}\right], \text{ and, } ¢_2 = 90^\circ.$$

Thus in the case of a U – shaped region of sensing, the total effective evanescent coefficient of absorption is given by:

$$¥_{eff} = [¥_{eff}(¤_1, ¤_2)]_{outer} + [¥_{eff}(¢_1, ¢_2)]_{inner} \tag{9}$$

The second term in the equation 9 vanishes, when only from the outer surface the total internal reflection occurs. As already mentioned above, the sensitivity is proportional to¥ /~ , for a given sensing region length, to evaluate the characteristics of the sensor, we calculate this ratio. The optical fiber so prepared is now ready to perform the experimental study to estimate the content of iodine in common salt solution. The experimental arrangement is shown in fig. 2.

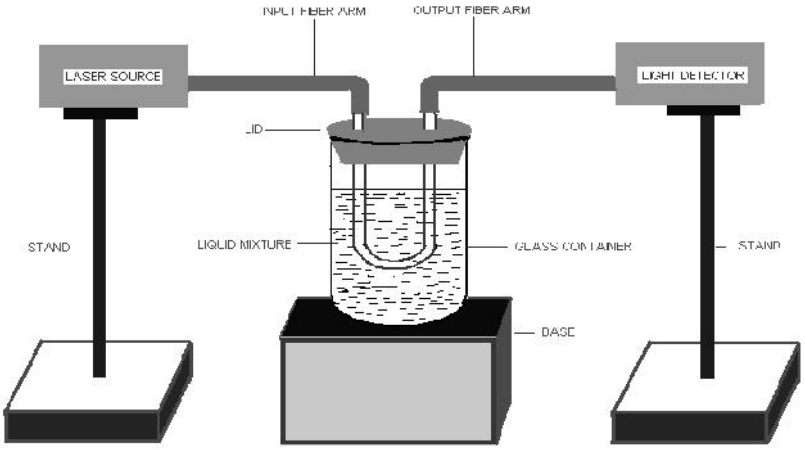

Fig. 2: Experimental arrangement of sensor

A known quantity of common salt dissolved in 100 ml of pure water will act as liquid cladding surrounding the U- shaped glass core of the fiber when the sensor is immersed in that liquid. By taking different concentrations of the mixture surrounding the U-shaped glass rod, the power output is recorded at an operating wavelength of 630 nm. Keeping the experimental arrangement as it is, the liquid cladding, which was common salt solution earlier, replaced with iodine salt solution now. By increasing the concentration of iodine salt solution surrounding the U-shaped glass rod core, the changes in the output power is recorded again and tabulated against concentration of the liquid. In both the cases, namely common salt solution and iodine salt solutions, the power output versus concentration of the solution surrounding the U-shaped glass core, are graphically represented at an operating wavelength of 630 nm [Fig. 3. Initially, a 15 mg of Potassium Iodide is dissolved 3125 ml of pure distilled water, which corresponds to 32 gram in 100 ml. then 1 Kg. of common salt is added so that the solution prepared contains 15 parts per million (ppm) of KI. Then the U-shaped glass rod of 7 cm is immersed into this mixture, then the light is launched into the input fiber of the sensor and the power reaching the detector in recorded. Secondly, another 15 mg of KI is dissolved in the first solution, to make the solution to 30 ppm of KI. The mixture so prepared maintained surrounding the U-shaped glass core of the sensor of 7 cm height and output power is recorded. The experiment is further repeated for 45, 60, 75, 90 ppm of KI. The output power is noted tabulated again. The graph is drawn between ppm of KI, and the power output. The experiment is repeated further for 24 gm, 16 gm, and 4 gm of KI, by noting the power output at each concentration (Fig. 4).

3. RESULTS AND DISCUSSION

From graph in figure 3, it can be observed that the power output for a given concentration of 4 grams of common salt dissolved in 100 ml of distilled water is -48.22dBm and at the same concentration of iodine and salt solution, the output power is -49.60 dBm for the 7 cm U-shaped glass rod core dipped in the above solutions. The variation in the output power for the above two solutions with an upper limit of 32 gm in 100 ml distilled water for common salt and iodine salt is 49.60 and -49.42 dBm. This indicates the variation in output power in case of iodine salt is about -0.82 dBm, while in the case of common salt is -0.78 dBm.

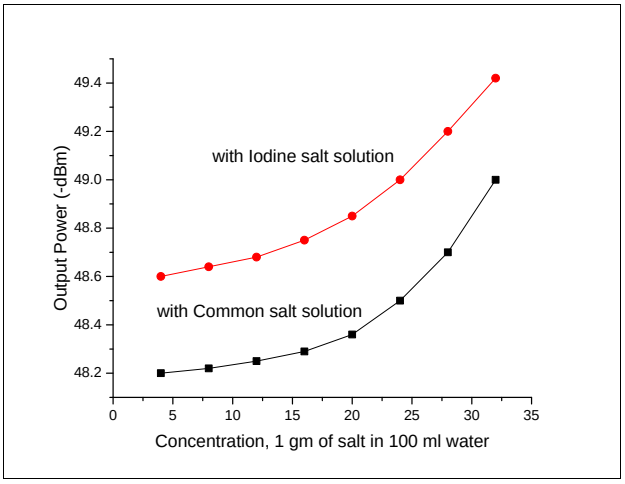

Fig. 3: Graph showing the concentration Vs Power Output at 630 nm for 7 cm U-shaped glass rod exposed in common salt and iodine salt solution

The graph in figure 4, gives a representation of output power versus the ppm of KI solution dissolved in ordinary salt solution. The KI variation from 15 ppm to 150 ppm is taken and the corresponding power output for solution concentrations of 4 mg, 16 mg, 24 mg, and 32 mg of common salt dissolved in 100 ml of distilled water is recorded. It may be observed from the graph that for a 15 ppm of KI, the power output variation is from -48.58 dBm to 49.39dBm for concentration variation of 4 gm to 32 gm of common salt dissolved in 100ml of distilled water. Similarly for KI of 150 ppm variation, the power output variation from -51.5 dBm to -52.5 dBm for concentration variation of 4 gm to 32 gm of common salt in 100ml distilled water. For all other ppm of KI, the variation of powers lie between these two extreme limits for respective concentrations of solutions. The information from the graph provides a mechanism for calibrations of output powers with respect to the ppm of KI in common salt solution. Thus the the method provides a common mechanism for the estimation of KI present in the iodine salt solution and one can estimate the iodine content knowing the molecular weights of potassium and iodine. The results so obtained are further confirmed by the chemical analysis.

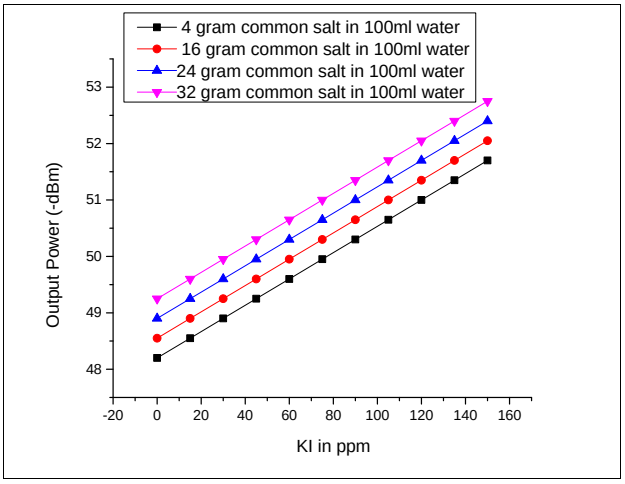

Fig. 4: Graph between KI in ppm and power output for 7 cm U-shaped glass rod core fiber exposed in KI salt solution at 630 nm.

4. CONCLUSIONS

The content of Iodine in the Iodized salt, supplied commercially for domestic purpose, can be determined and can be estimated using the present experiment by noting the power output coupled through the fiber output, when the solution with the above salt surrounds the core. From the standard calibrated graph knowing the output power one can easily estimate the ppm of other salts present in salt solutions. The same technique also can be used in the food processing industry as this technique offers potential applications to determine the iodine content.

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